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Fork et al.

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(54) **STUD BUMP SOCKET**

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(51) **Int. Cl.**
H01R 12/00 (2006.01)

(52) **U.S. Cl.** **439/74**

(58) **Field of Classification Search** 439/74, 439/82; 174/254, 260–262, 265, 267; 361/769, 361/767, 772, 774, 777
See application file for complete search history.

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(74) *Attorney, Agent, or Firm*—Bever, Hoffman & Harms, LLP; Patrick T. Bever

(57) **ABSTRACT**

A socket for solderless connection between a stud-bumped IC chip and a host PCB. The socket includes a three-dimensional (e.g., cylindrical or cubical) hollow metal frame that is either free-standing or supported by an underlying patterned template structure. The metal frame includes side walls that extend away from the host PCB, and a contact structure located at the upper (i.e., free) end of the side walls. The contact structure defines an opening through which a stud bump can be inserted into a central chamber of the metal frame. The side walls and/or the contact structure are formed such that when the tip end of the stud bump is inserted into the central chamber, at least one of the base structure and the sidewall of the stud bump abuts the contact structure at two or more contact points.

16 Claims, 10 Drawing Sheets

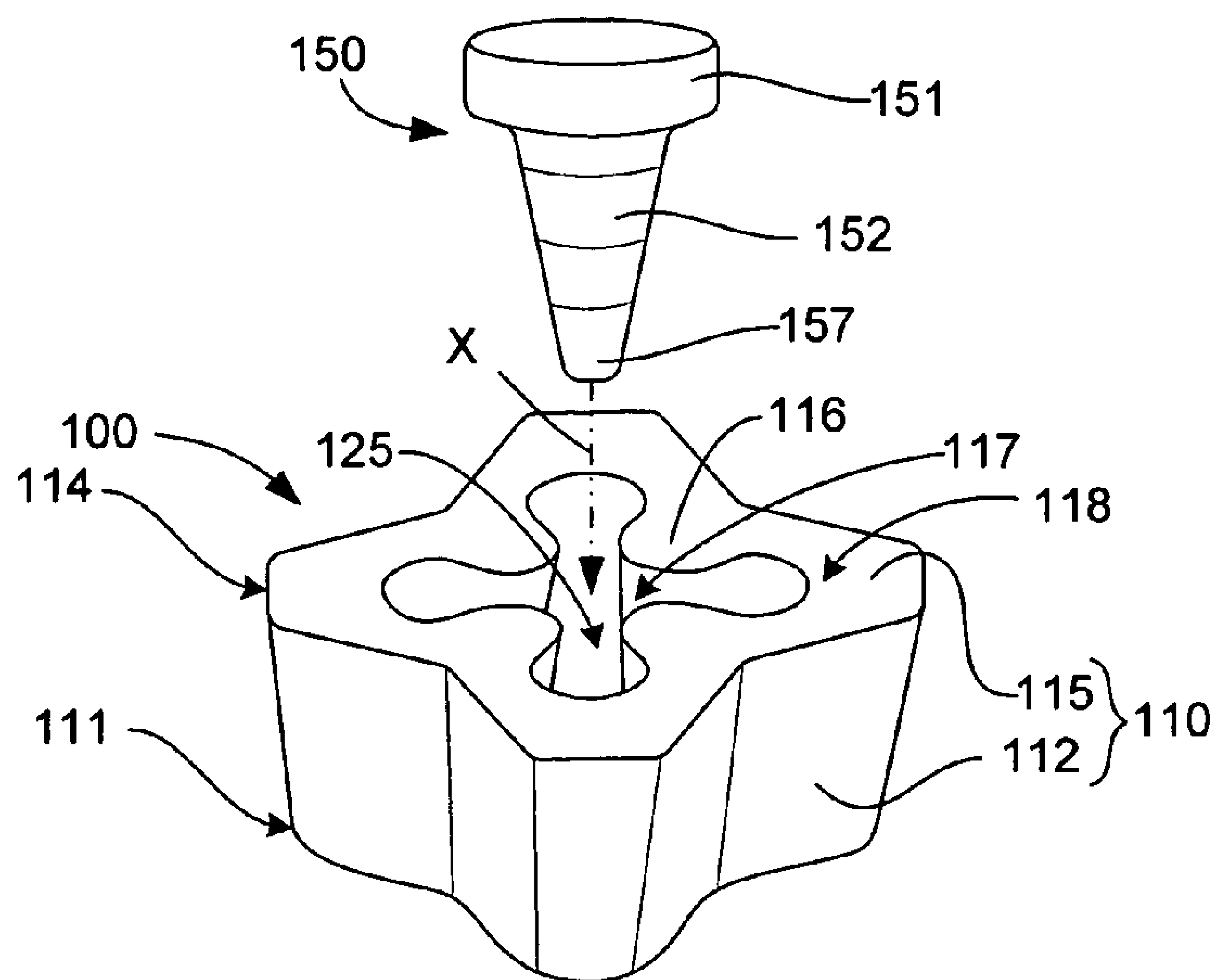


FIG. 1

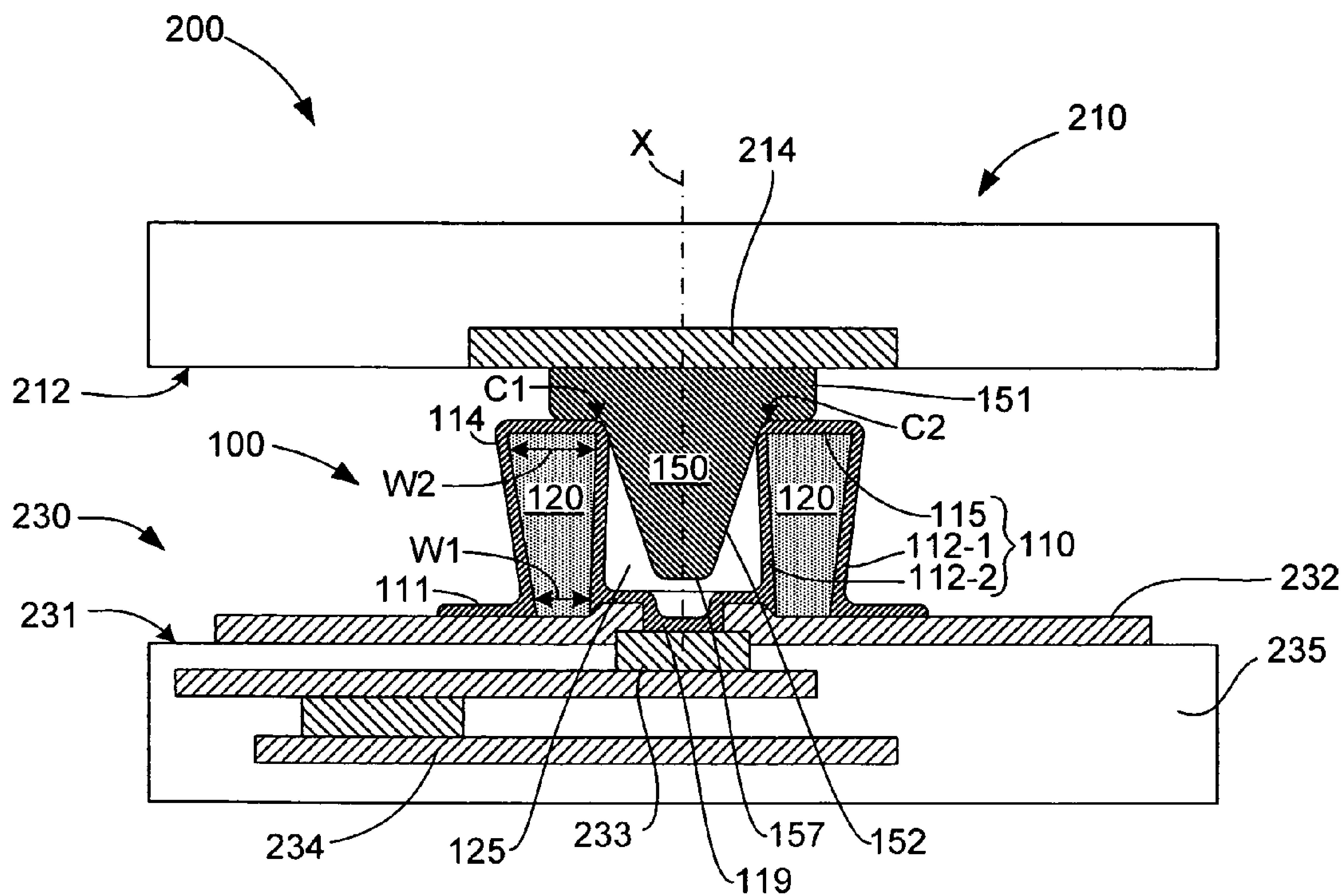


FIG. 2

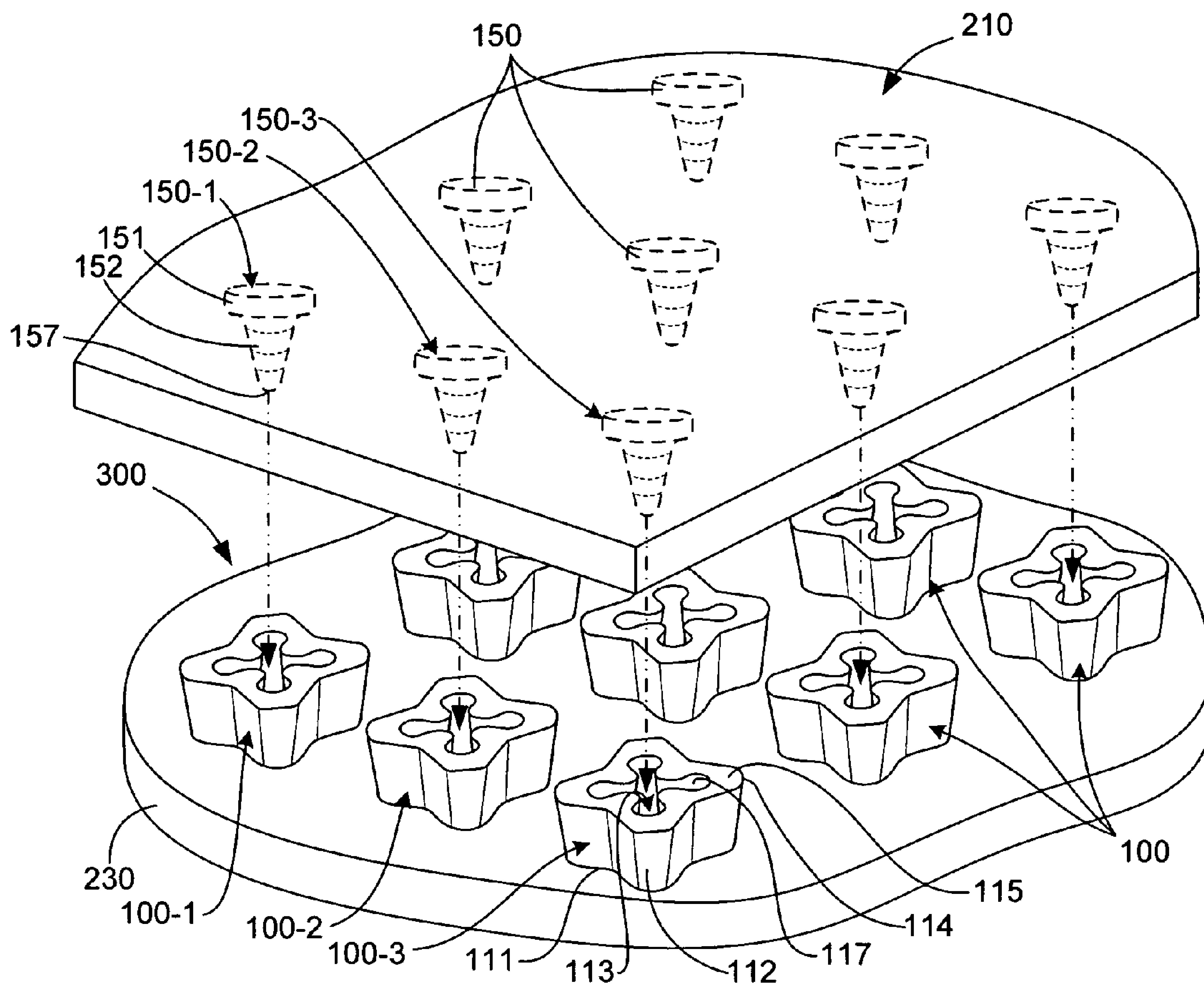


FIG. 3

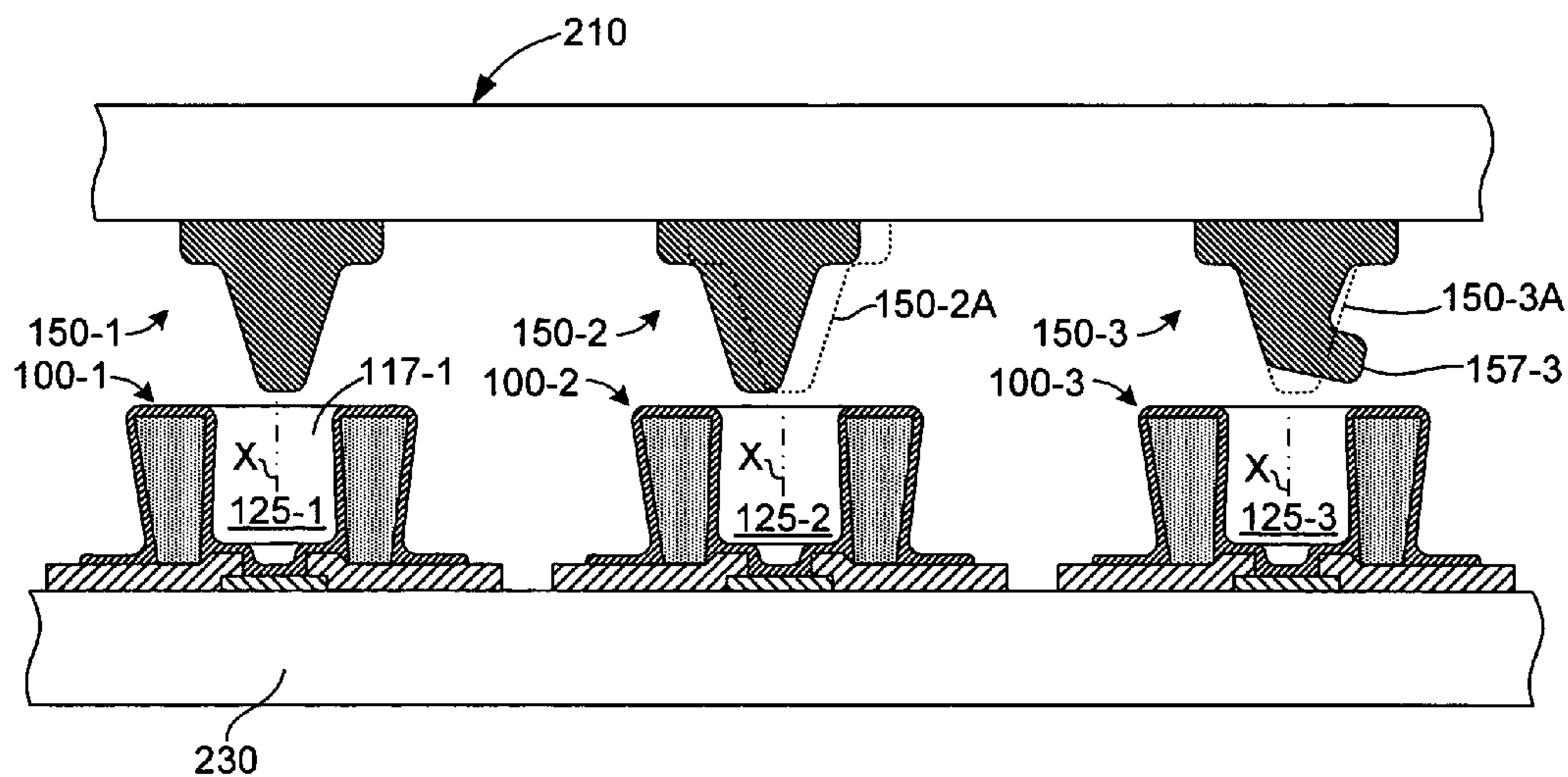


FIG. 4(A)

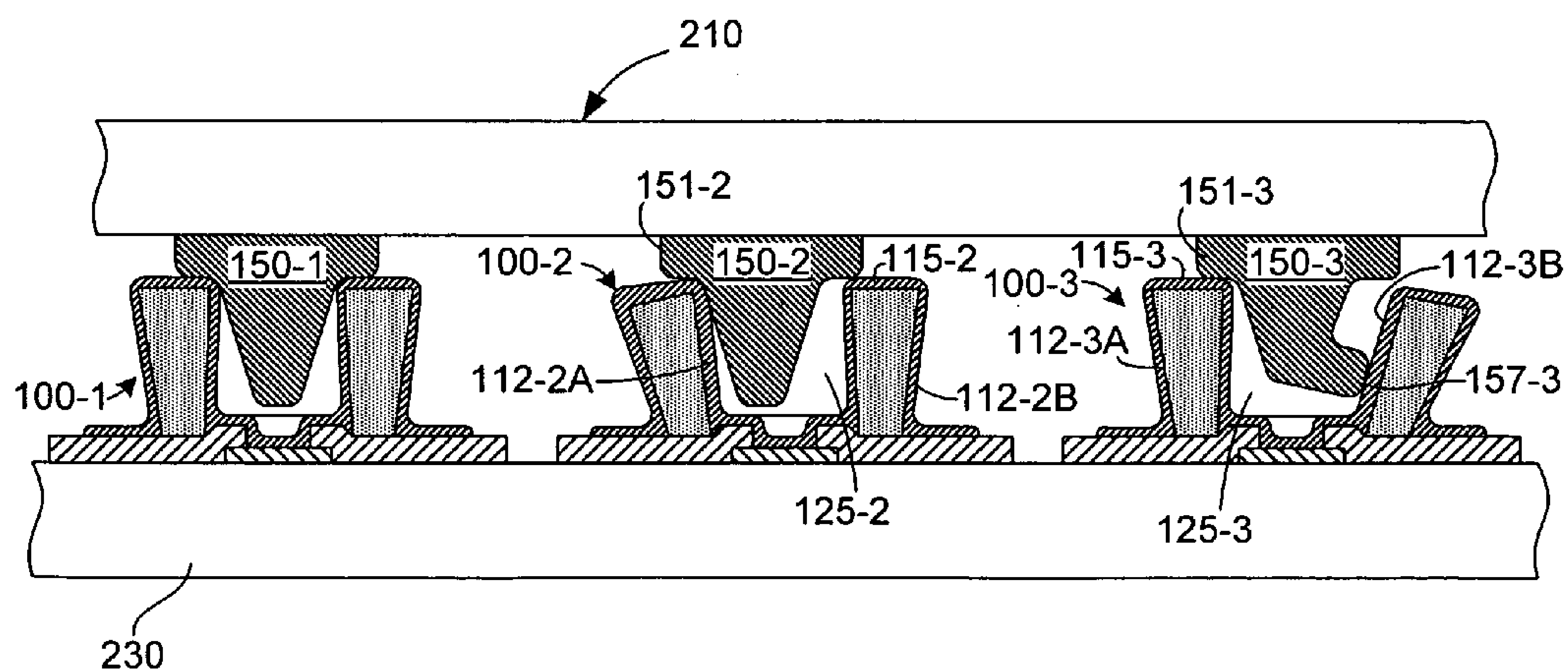


FIG. 4(B)

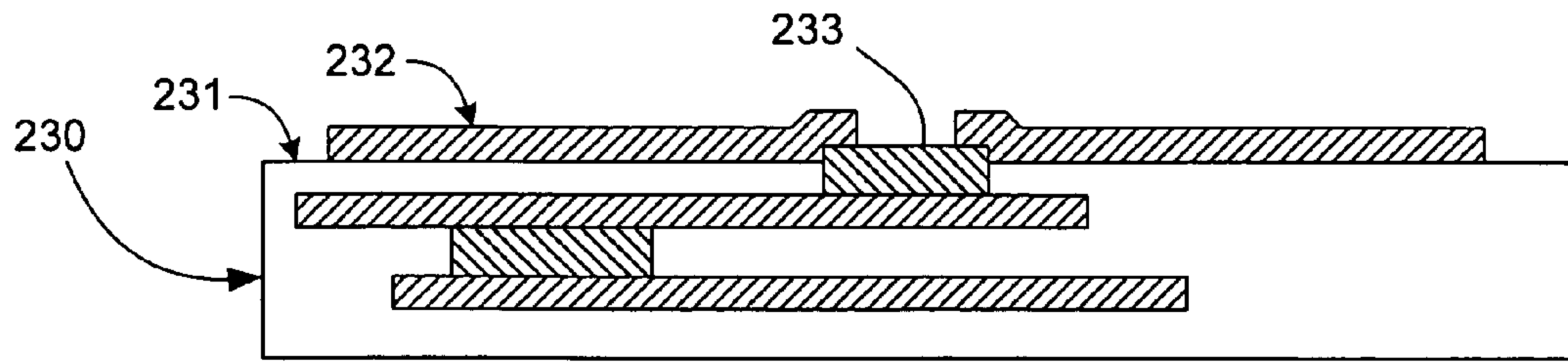


FIG. 5(A)

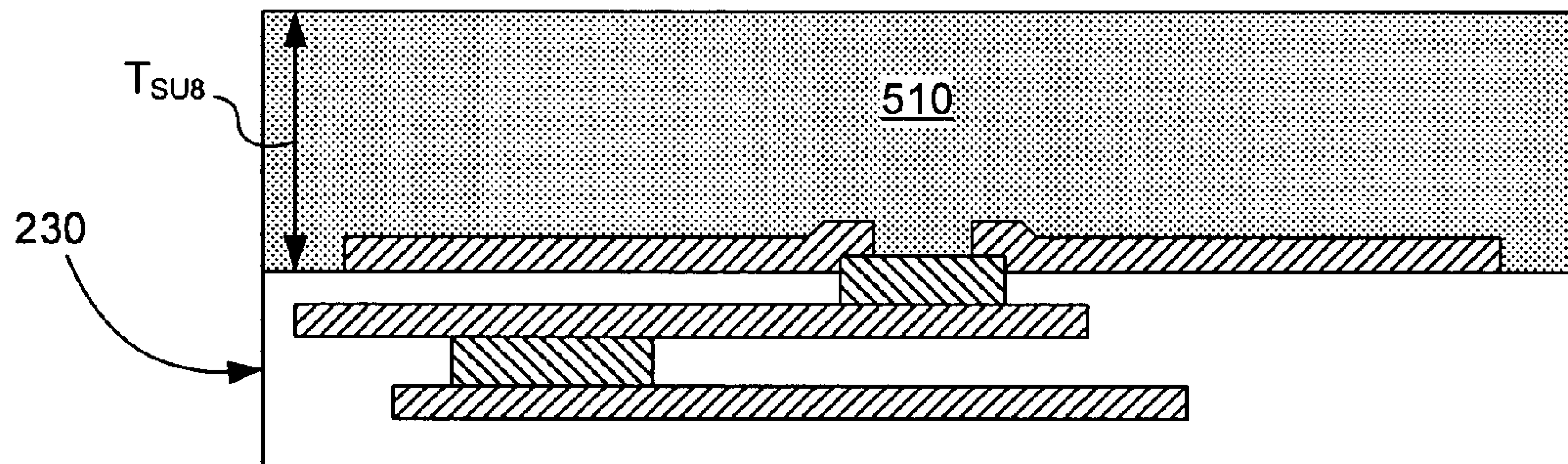


FIG. 5(B)

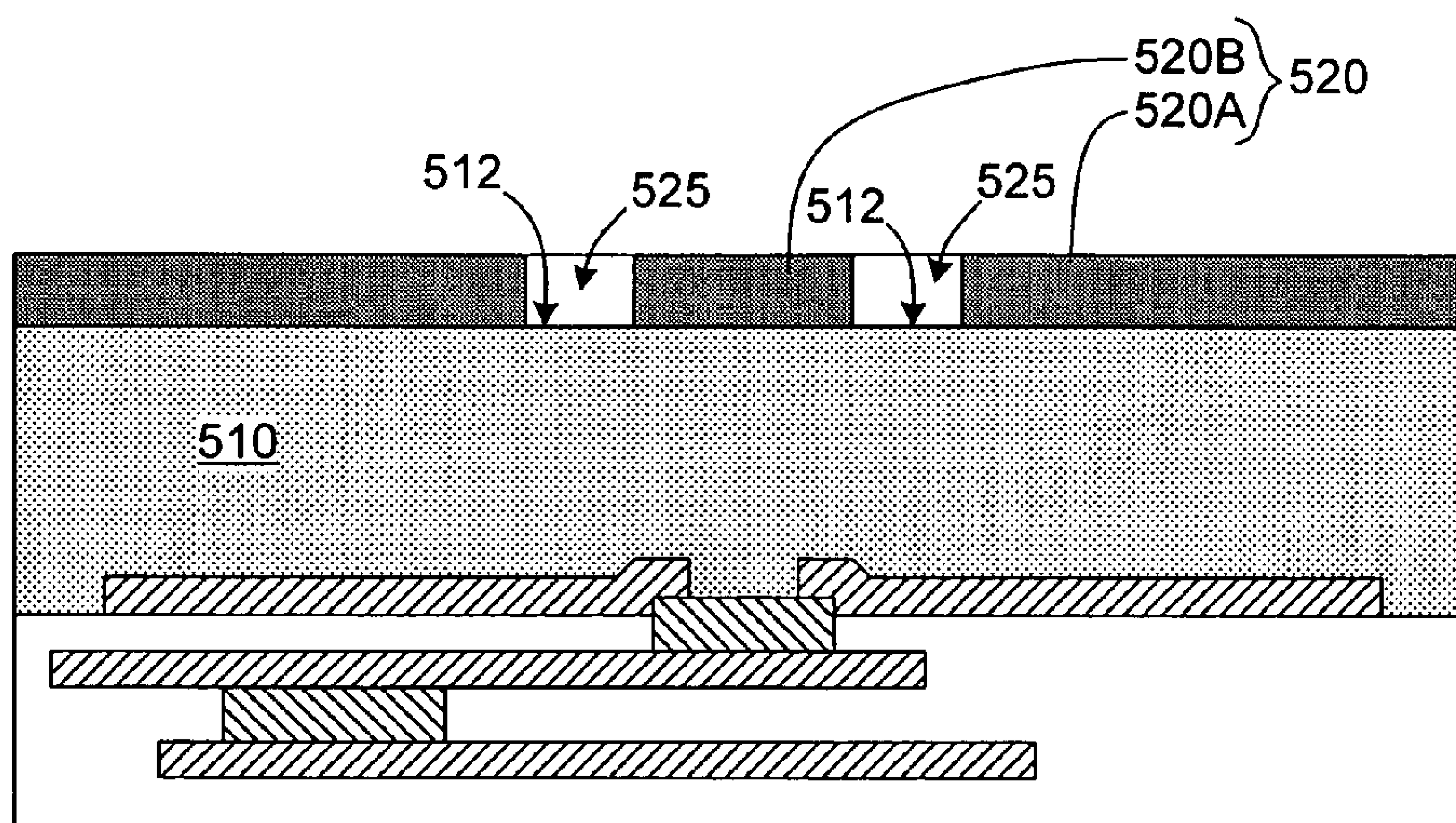


FIG. 5(C)

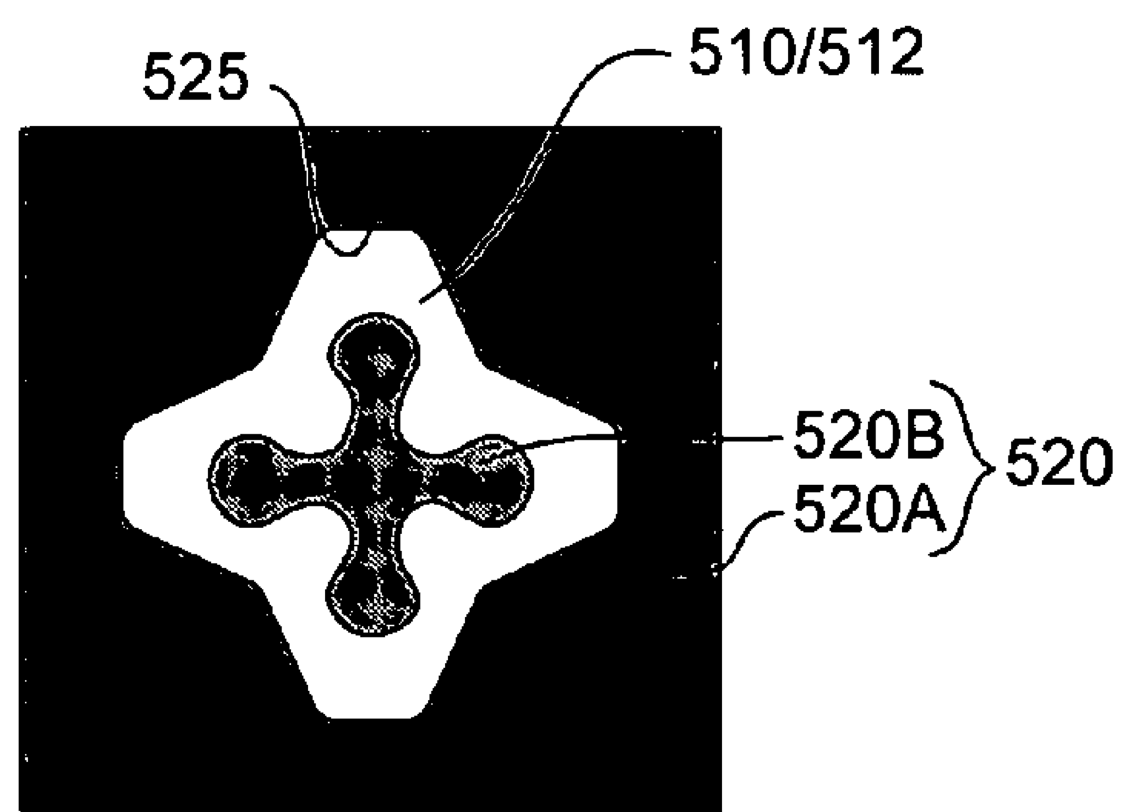


FIG. 6

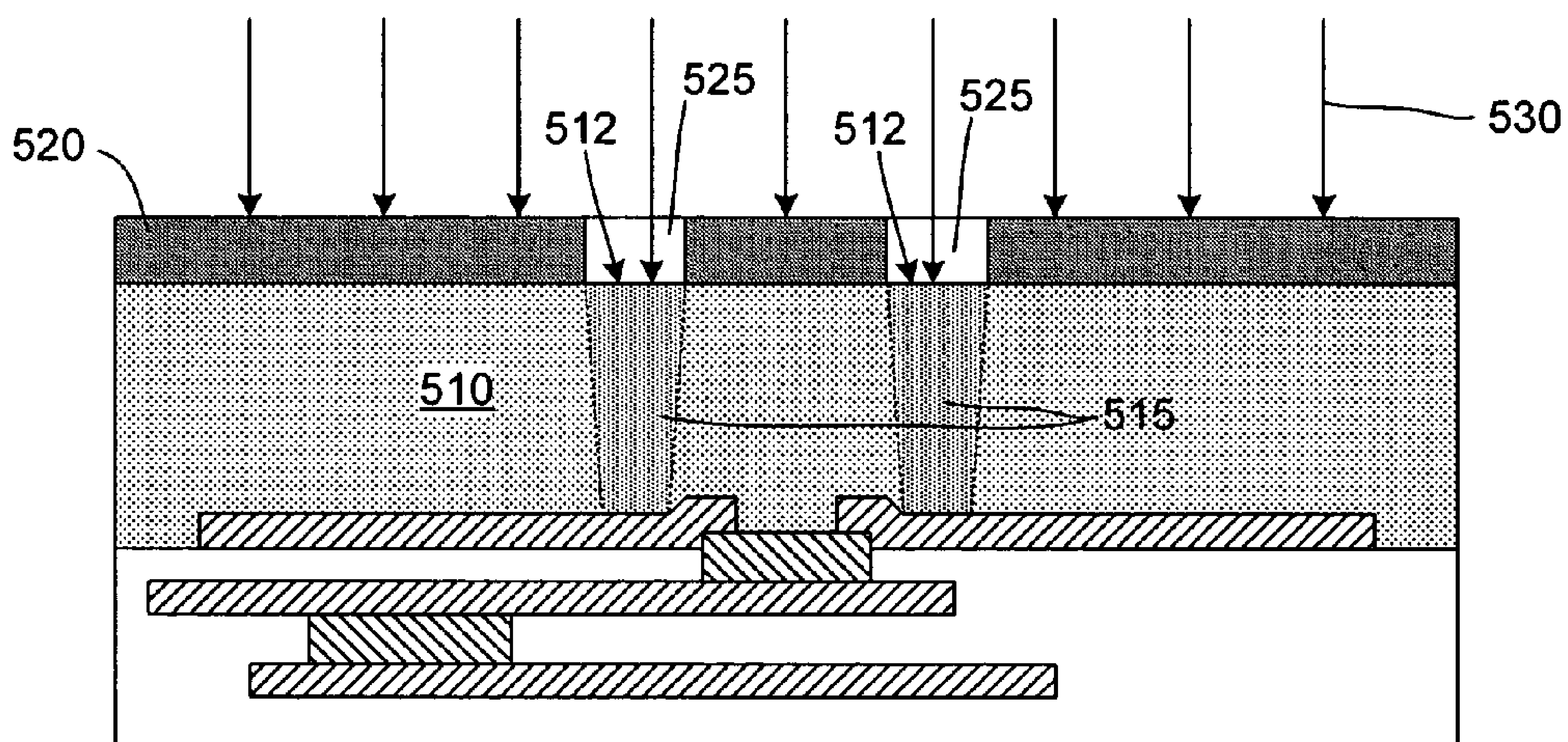


FIG. 7(A)

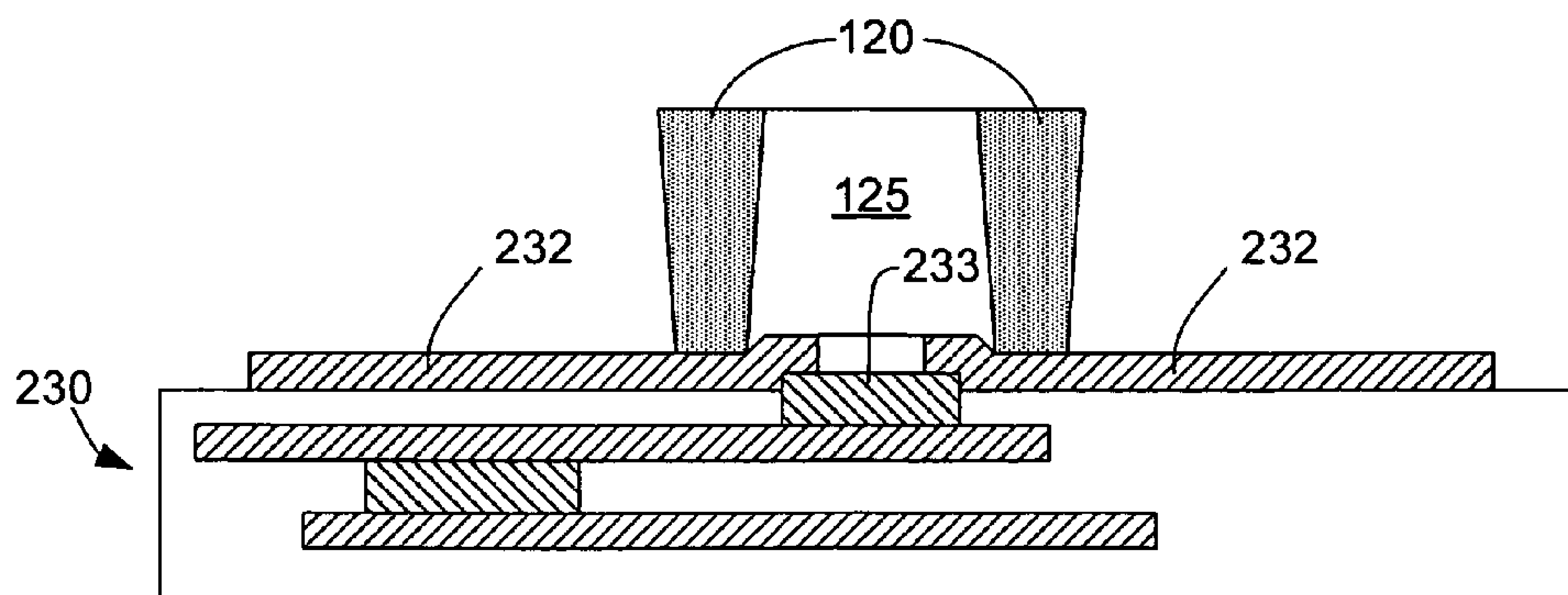


FIG. 7(B)

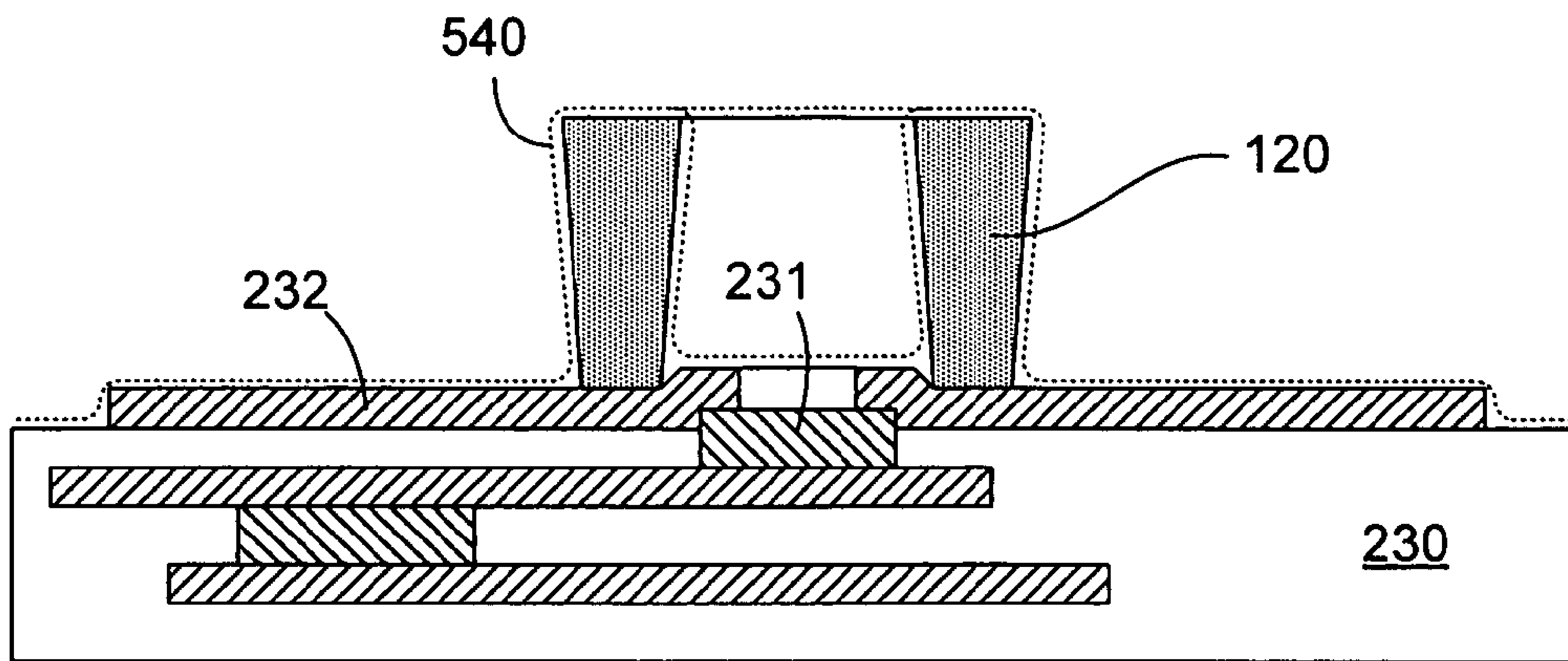


FIG. 8(A)

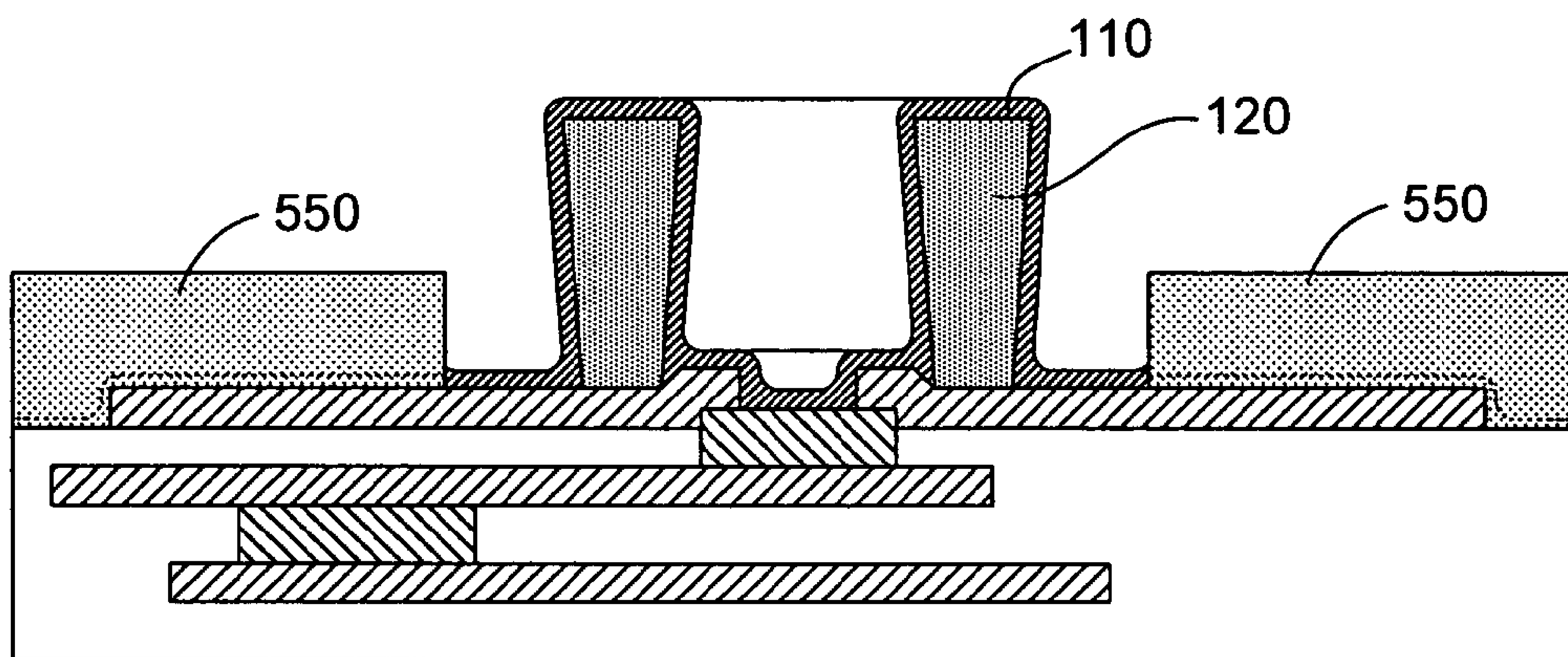


FIG. 8(B)

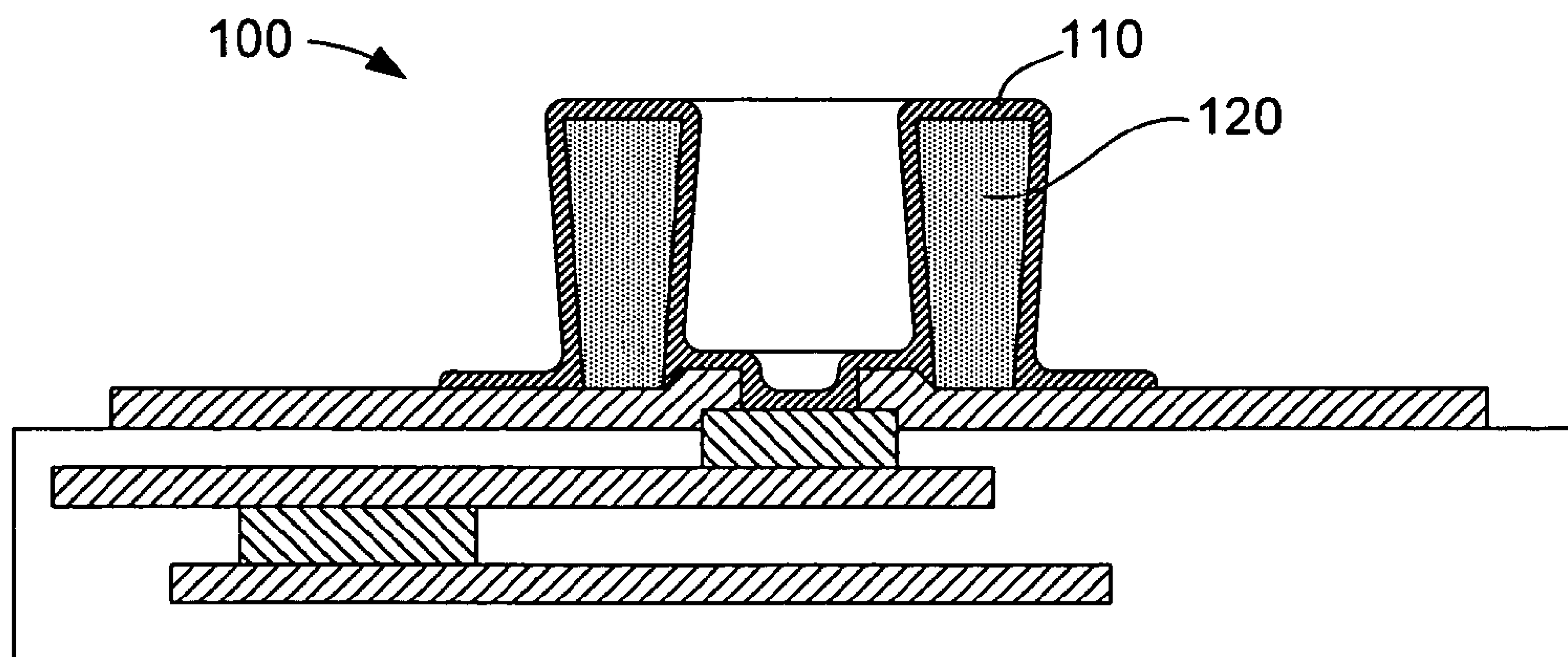


FIG. 8(C)

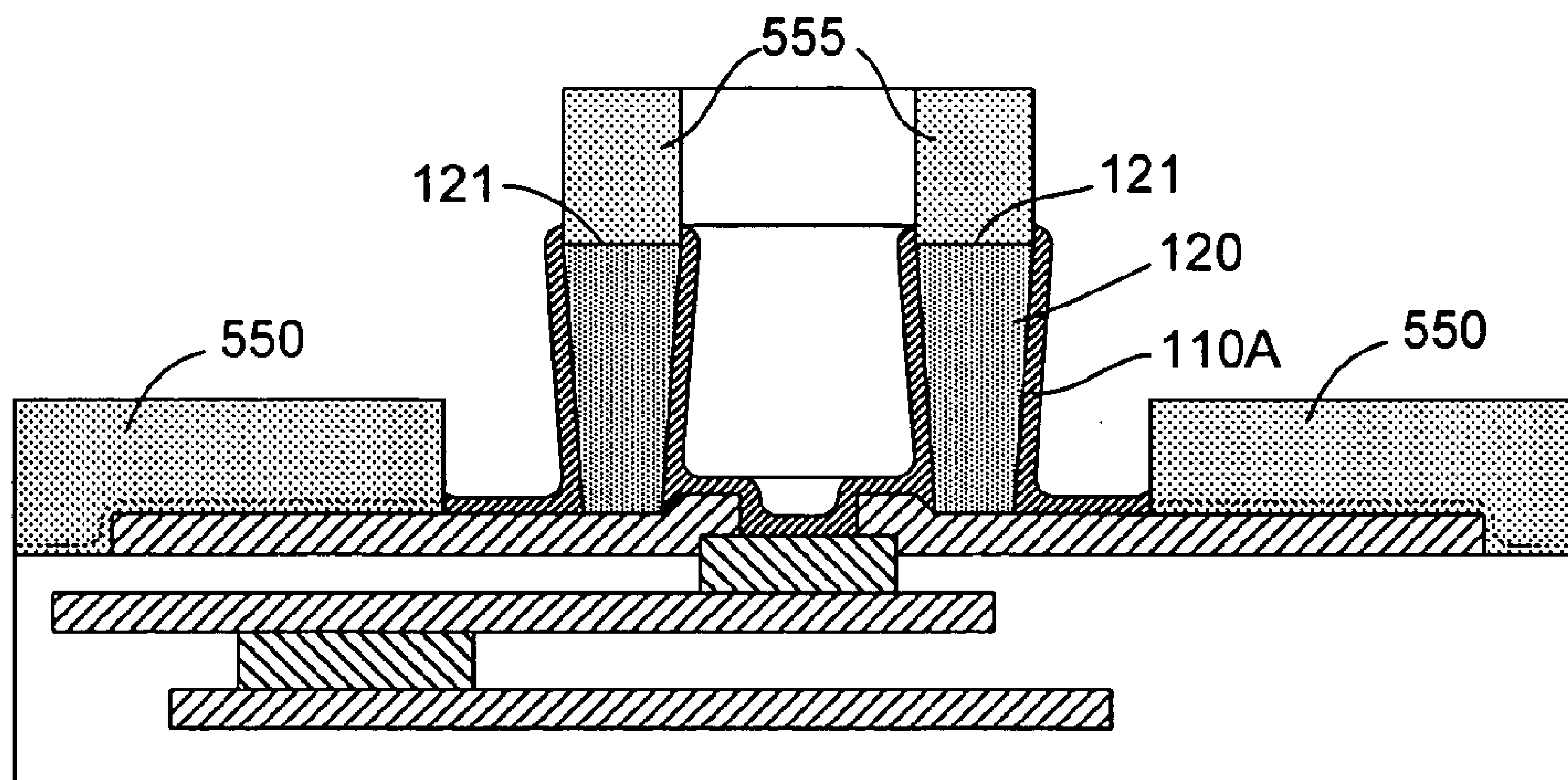


FIG. 9(A)

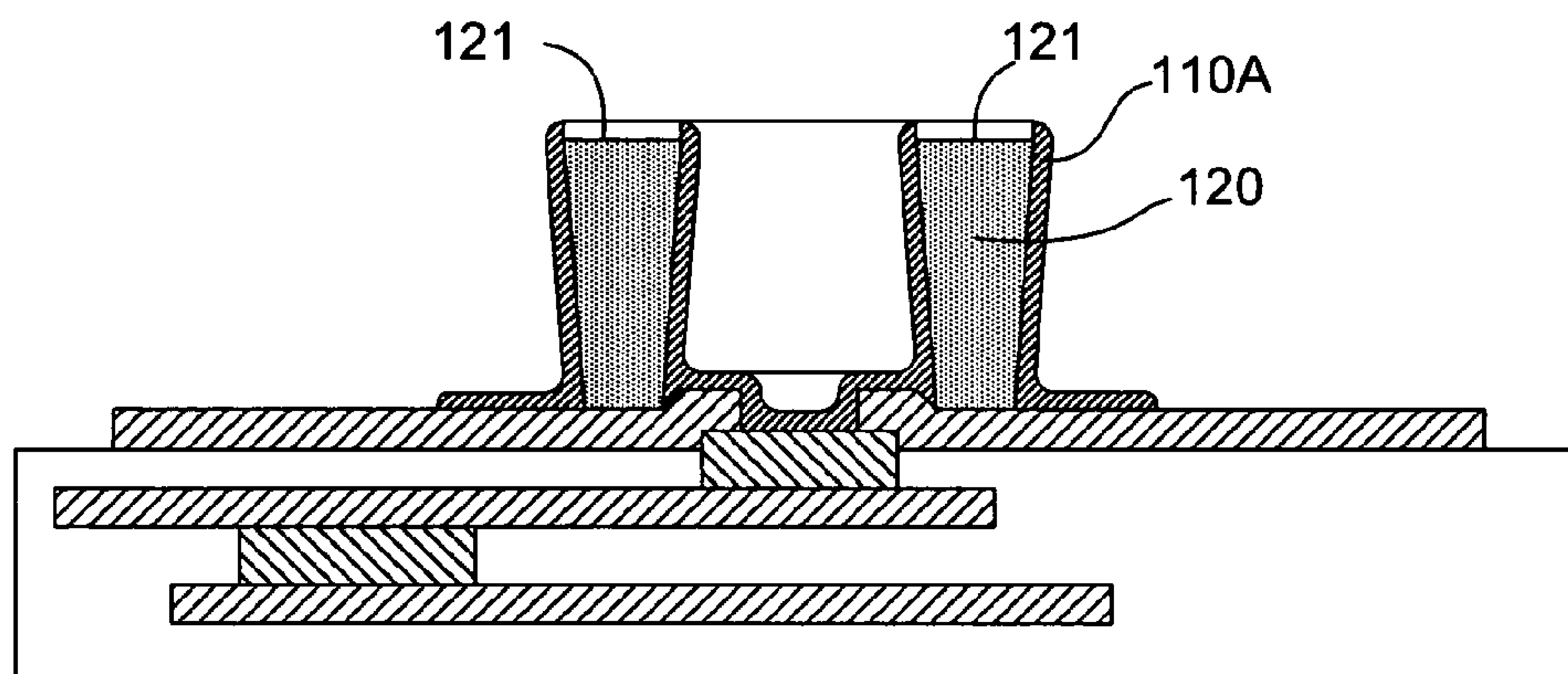


FIG. 9(B)

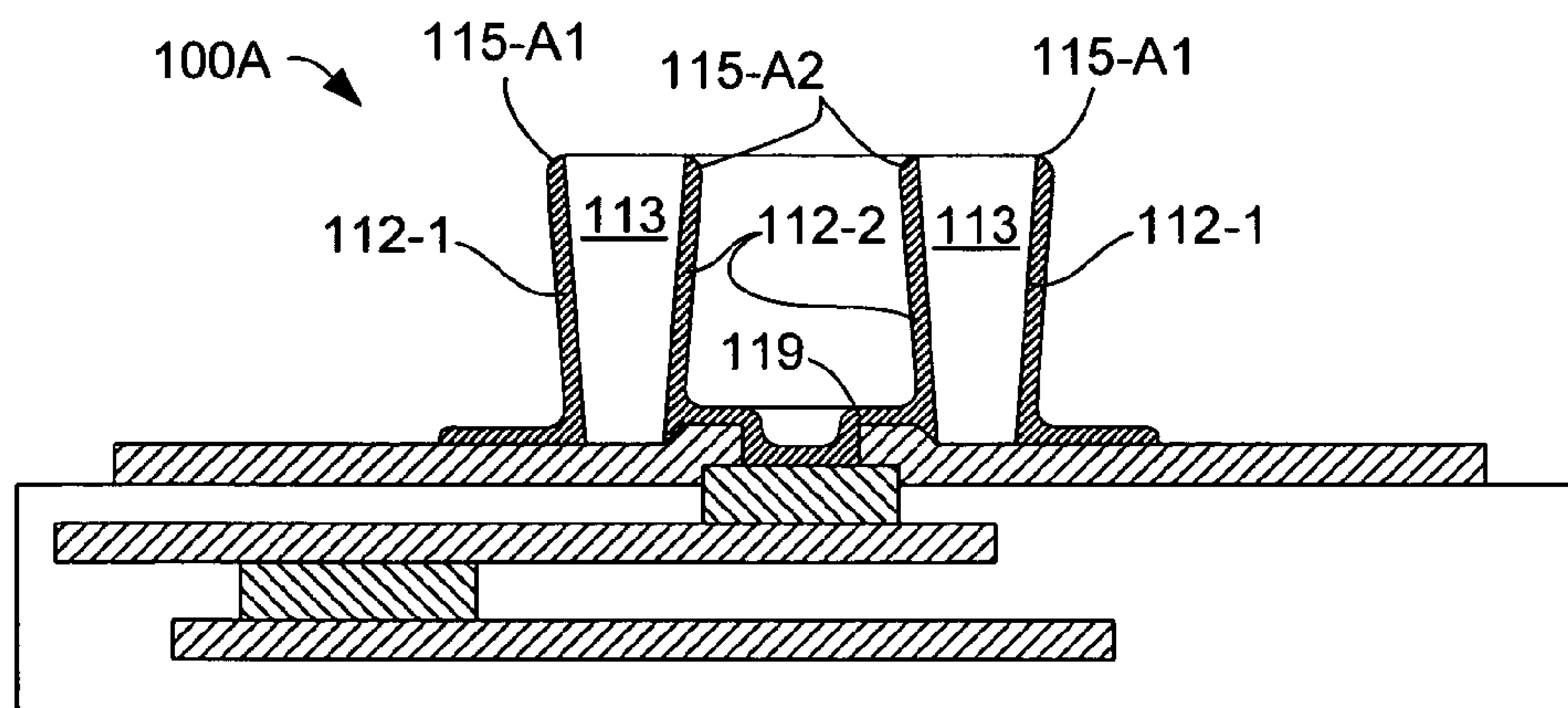


FIG. 9(C)

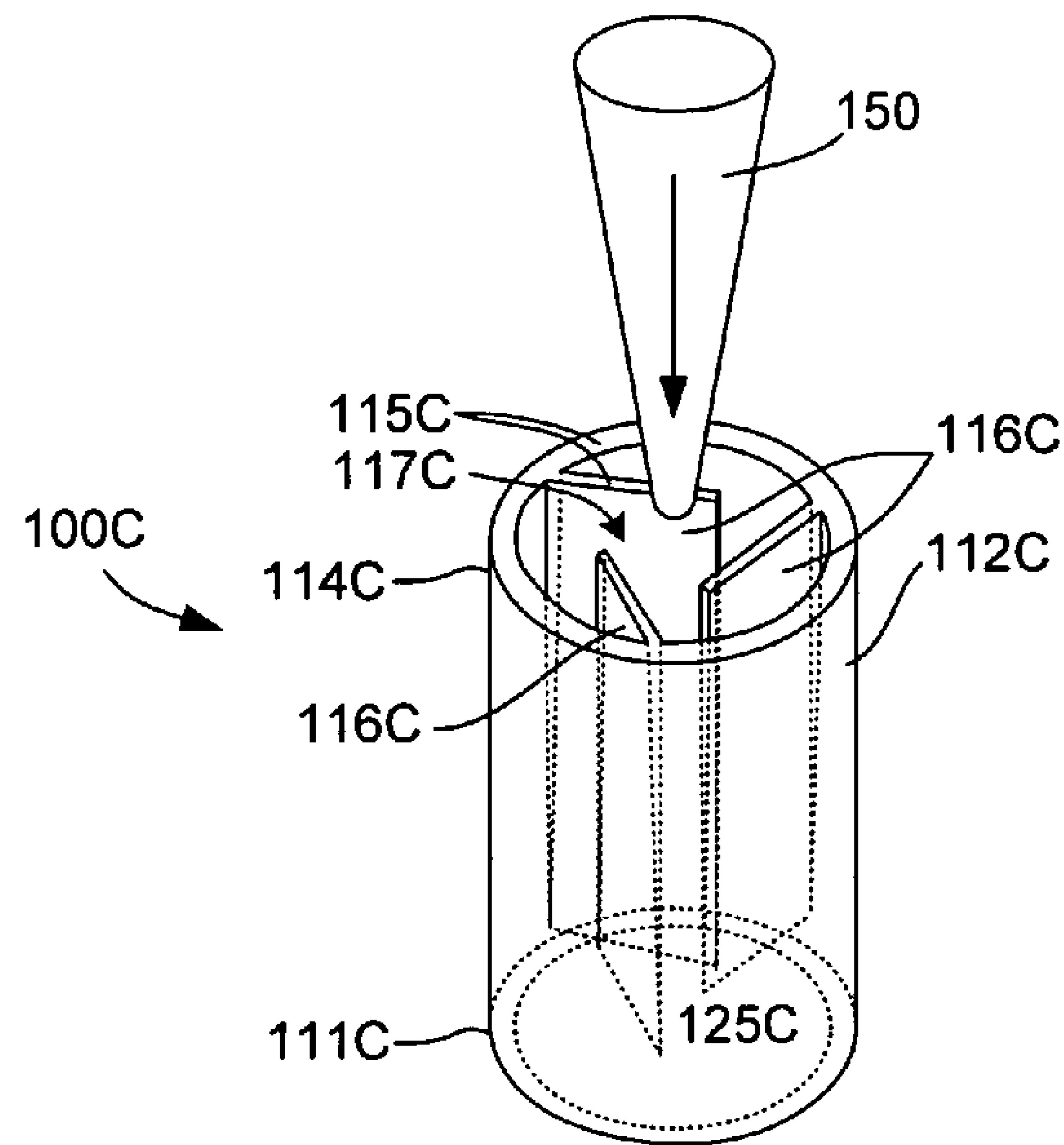


FIG. 10

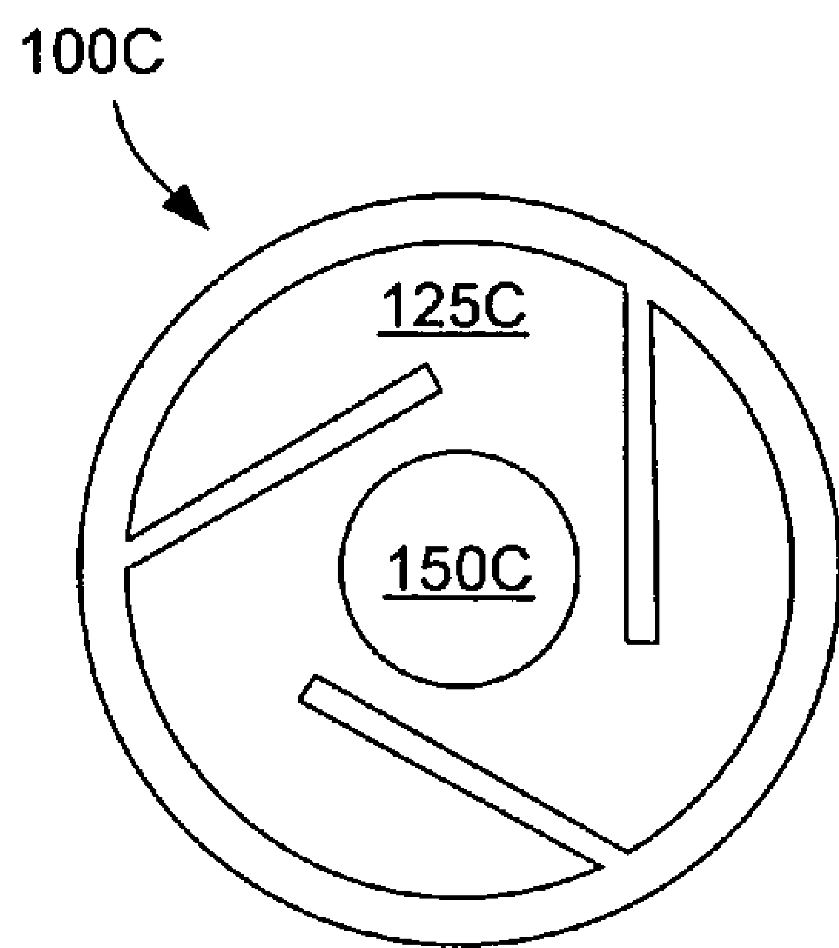


FIG. 11(A)

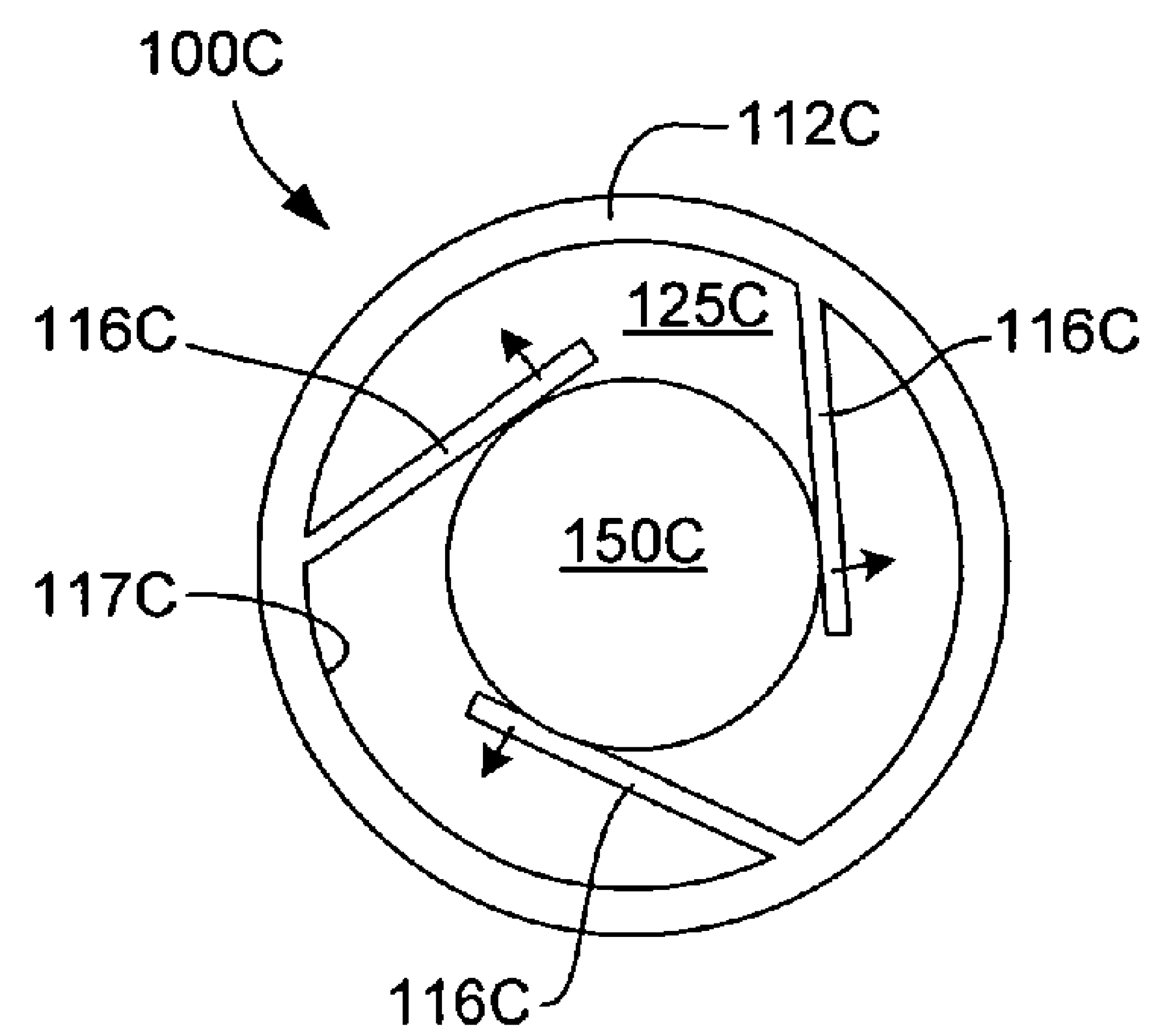


FIG. 11(B)

FIG. 12(A)

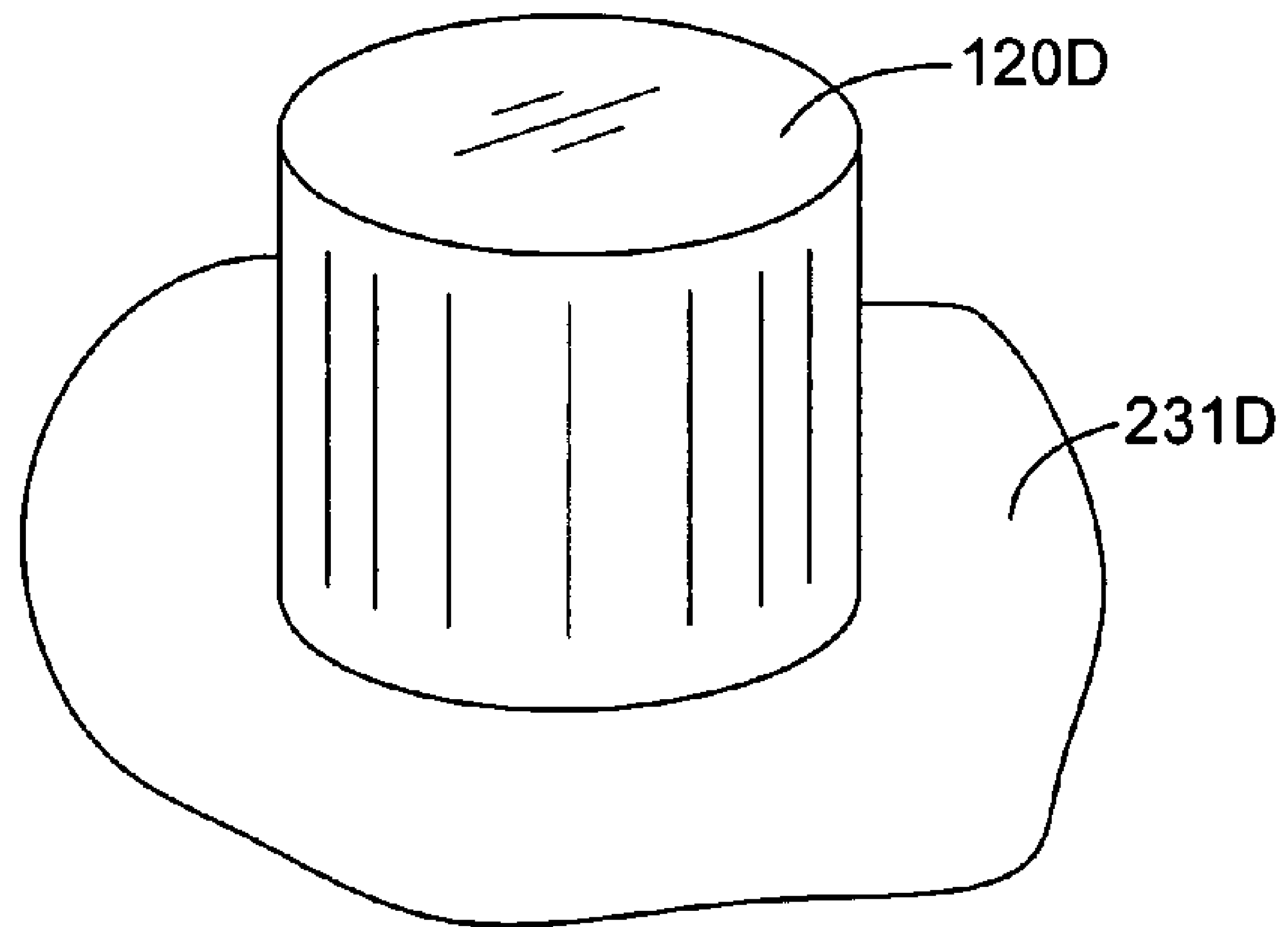


FIG. 12(B)

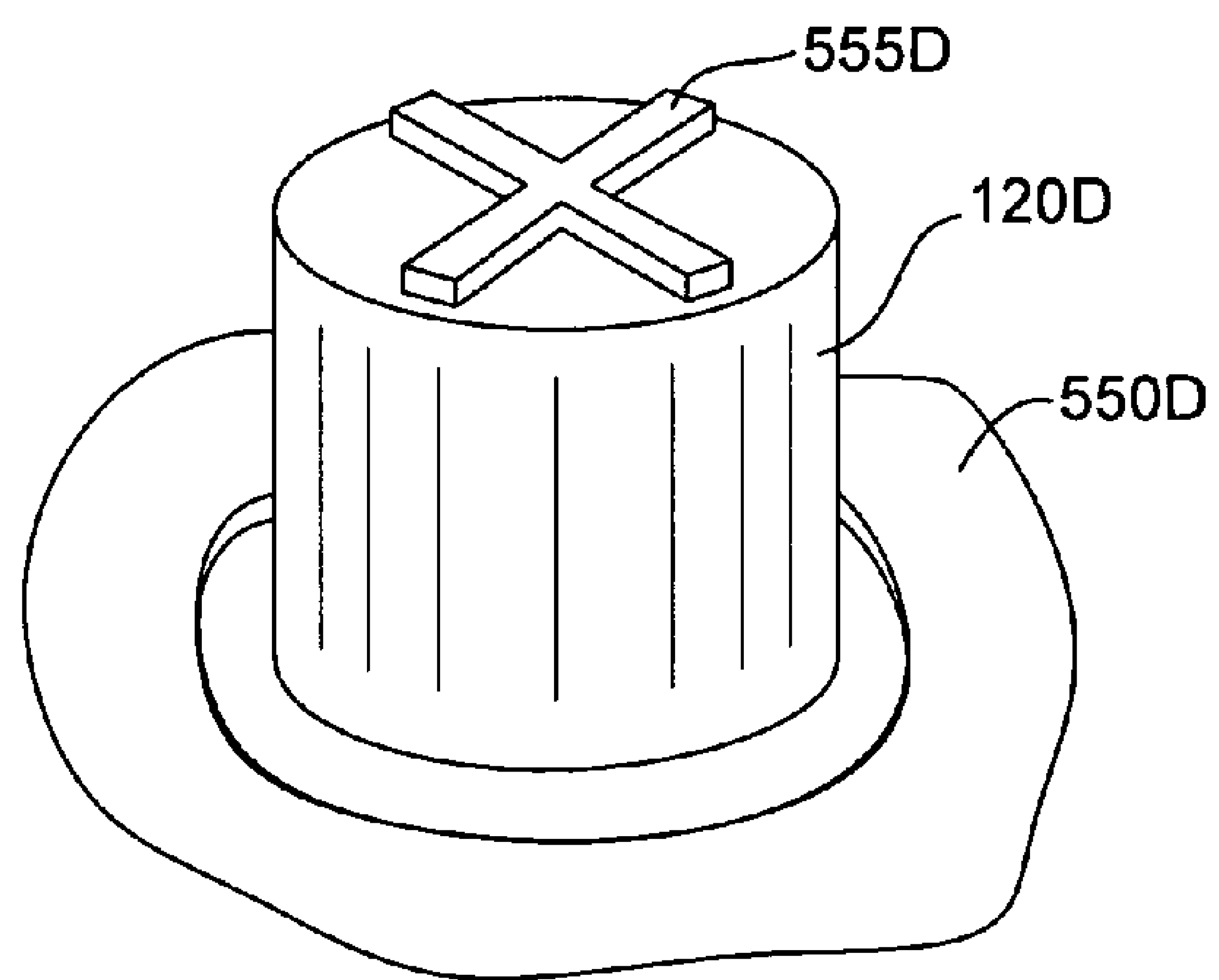
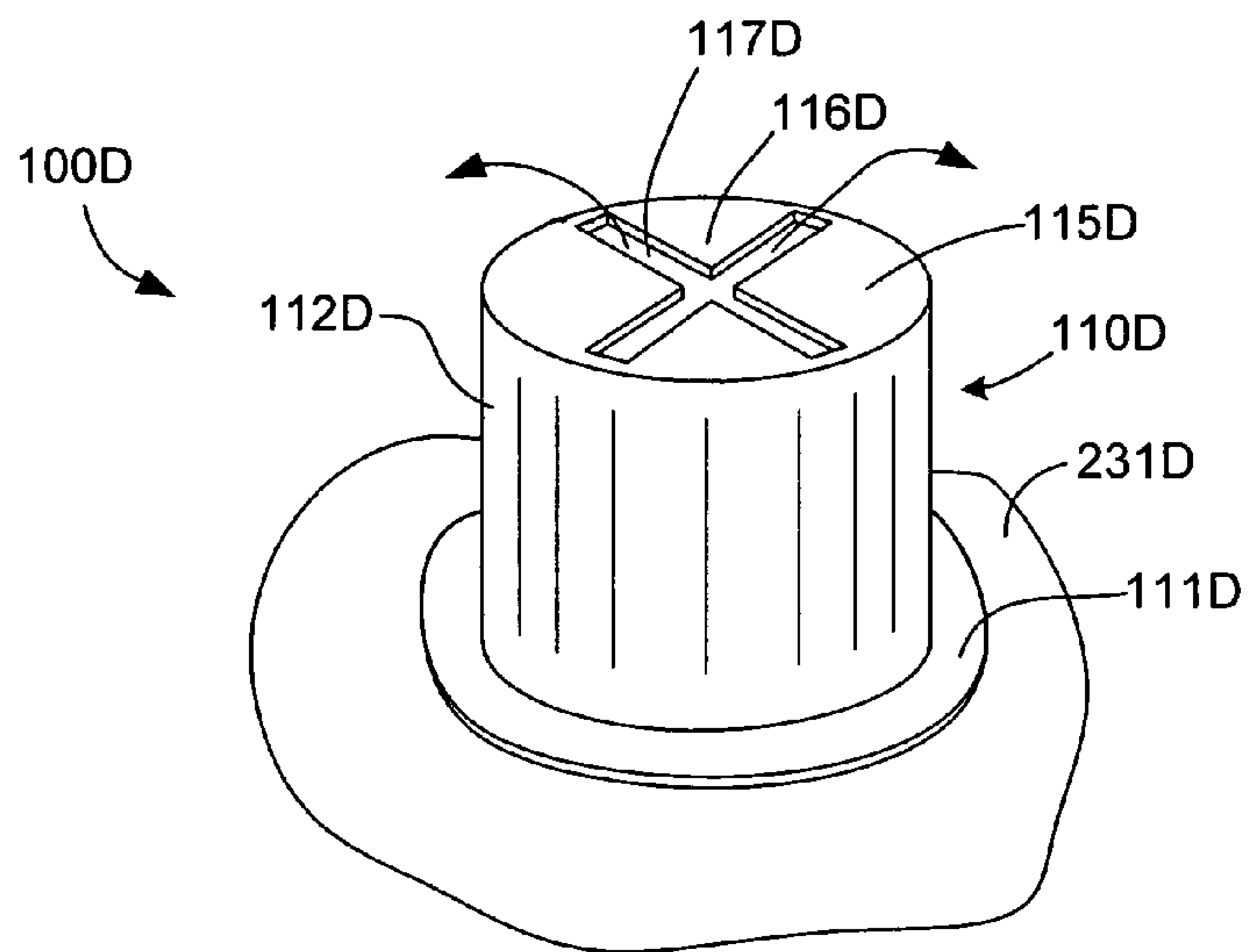


FIG. 12(C)



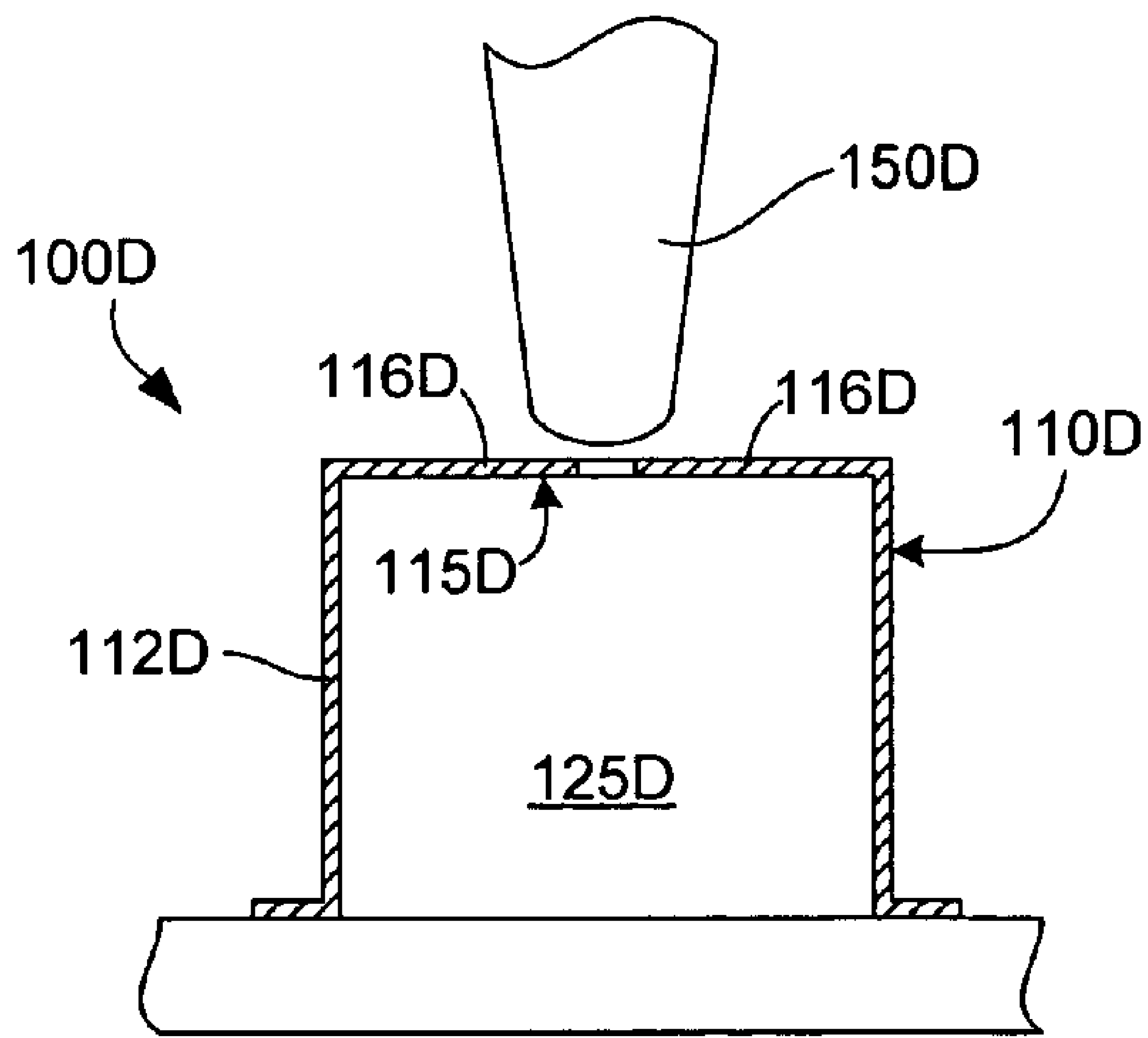


FIG. 13(A)

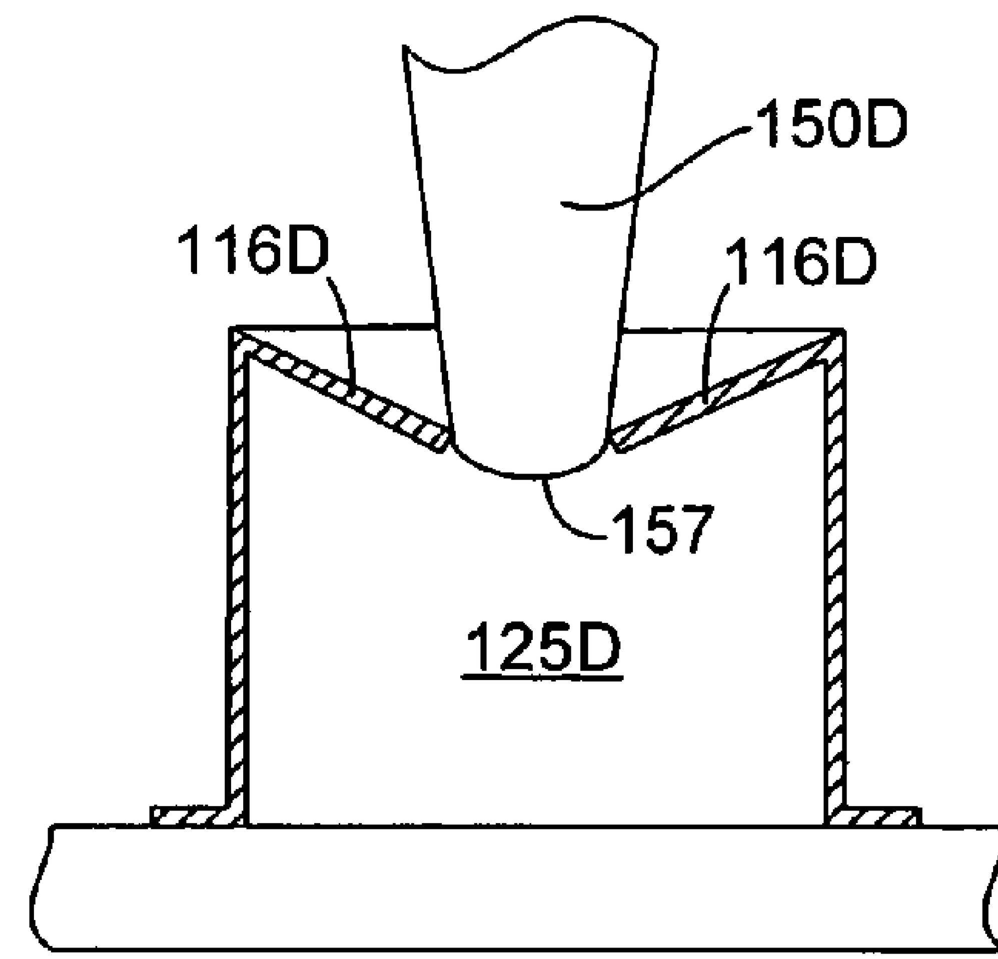


FIG. 13(B)

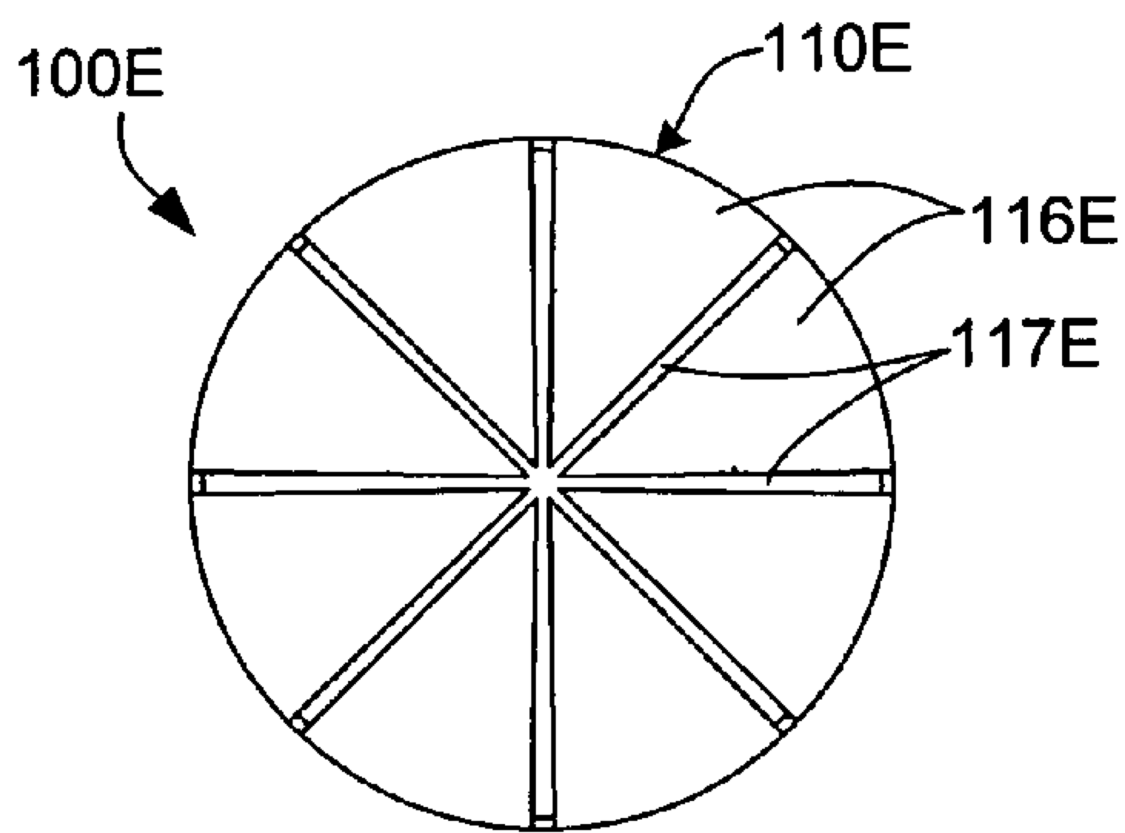


FIG. 14

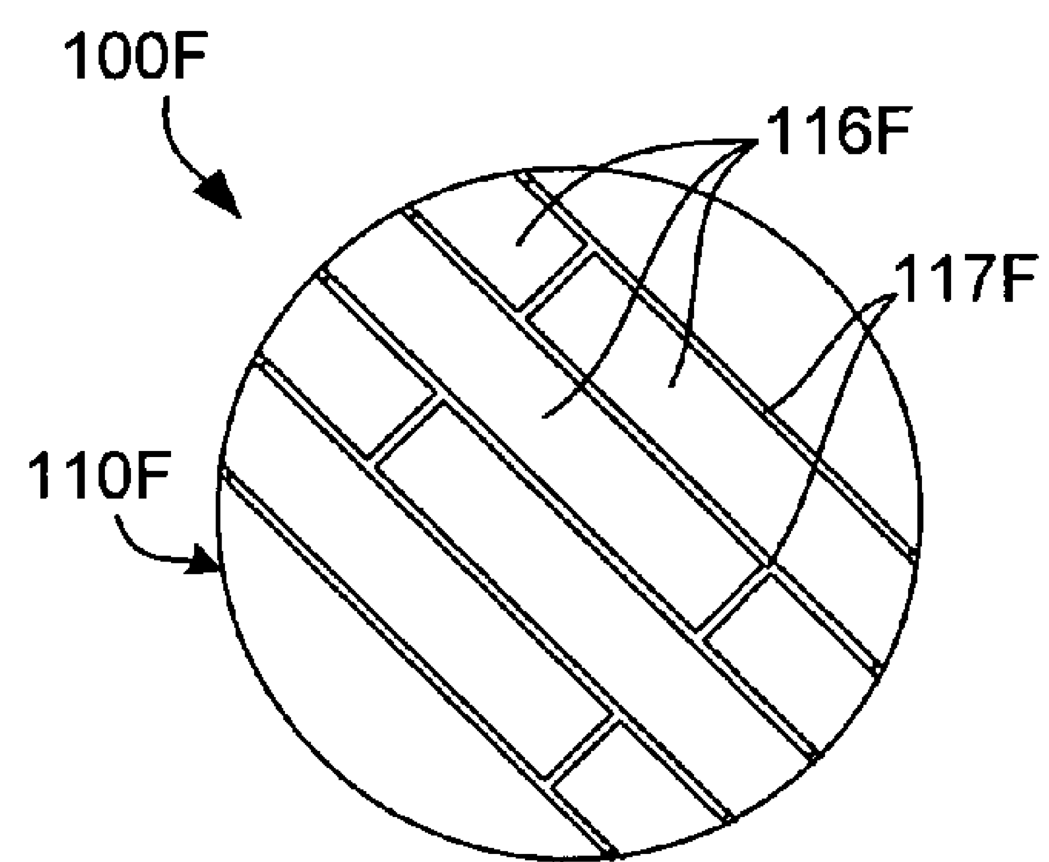


FIG. 15

STUD BUMP SOCKET

FIELD OF THE INVENTION

This invention relates to integrated circuit (IC) devices, and more particularly to structures for connecting IC devices to host systems.

BACKGROUND OF THE INVENTION

Electronic packages are interconnectable housings for integrated circuit (IC) devices. Packaging is performed after a semiconductor wafer has been fabricated according to known semiconductor processing techniques, and then "diced" (i.e., cut) into individual IC "chips". Typically, packaging involves placing one or more IC chips into a package housing, electrically connecting the IC chip to contact pads formed on the housing, e.g., by wire bonding these contact pads to corresponding input/output (I/O) die bonding pads formed on the IC chip(s), and then covering the IC chip and wire bonds for protection. The housings typically include multiple leads, pins, or bumps that are connected by conductive traces to the contact pads, and are arranged in a predetermined pattern such that the packaged IC chip can be tested by applying test signals to the leads/pins/bumps using a test fixture. Faulty IC chips are thus identified and discarded, while IC chips that pass this testing process are subsequently mounted (e.g., soldered) onto a corresponding contact site of another host system printed circuit board (PCB). If a packaged IC subsequently fails, the faulty IC can be removed from the host system by heating the solder to remove the faulty IC, cleaning the PCB contact site, and then resoldering a new packaged IC onto the contact site.

A problem associated with the conventional practice of packaging IC chips prior to testing is that the process of packaging damaged or otherwise non-functional IC chips significantly increases overall production costs. Currently, there are few chip-scale socket solutions capable of testing IC chips prior to packaging. Instead, most IC test socket technology consists of zero insertion force (ZIF) sockets, which are designed to facilitate the insertion and removal of a dual in-line package or pin grid array package without special tools. As such, these conventional ZIF socket solutions require packaging of each IC chip before they can be used, which increases overall manufacturing costs and thus reduces profitability.

Therefore, compliant, reworkable IC chip connections are a highly desired technology for testing and burning in the IC chips prior to packaging. In addition to making assembly and rework simpler and faster, such connections could facilitate the circumvention of tariffs on imported computer parts (e.g., lap top computers can be shipped separately from their processors, and hence get taxed as parts rather than as completed computer systems).

Flip-chip technology is growing in popularity because of its high input/output density capability, increased chip-packaging density, and excellent electrical performance. Solder-bumped, flip-chip technology has been well established since IBM developed the C4 process. In this process, solder bumps were formed on under-bump metallurgy (UBM) pads on the chip and joined to matching metal pads on the substrate by a reflow process. Because the established technique involves difficult and expensive processes to implement, new low-cost techniques for flip chip connections were sought.

Recently, the stud-bump bonding (SBB) technology, which is based on the wire-bonding technology, has been developed as a very attractive solution for a low-cost flip-chip technology. With SBB technology, gold stud bumps are placed on the die bond pads of IC chips through a modification of the "ball bonding" process used in conventional wire bonding. In ball bonding, the tip of the gold bond wire is melted to form a sphere. The wire-bonding tool presses this sphere against the aluminum bond pad, applying mechanical force, heat, and ultrasonic energy to create a metallic connection. The wire-bonding tool next extends the gold wire to the connection pad on the board, substrate, or lead frame, and makes a "stitch" bond to that pad, finishing by breaking off the bond wire to begin another cycle. For gold stud bumping, the first ball bond is made as described, but the wire is then broken close above the ball. The resulting gold ball with truncated wire, or "stud bump", remains on the bond pad to provide a permanent, reliable connection through the aluminum oxide to the underlying metal. This technology has several advantages: UBM process is not necessary, bumping cost is low, and fine-pitch and chip-level bumping is possible.

Gold stud bump flip chip technology offers several advantages over conventional IC packaging. The bumping equipment, a wire bonder or dedicated stud bumper, is widely available and well characterized. Since stud bumps are formed by wire bonders, they can be placed anywhere a wire bond might be placed. They can easily achieve pitches of less than 100 microns and be placed on pads of less than 75 microns. Since stud bumping can be done on a wire bonder, it does not require wafers or under-bump metallization (UBM). Single, off-the-shelf die can be bumped and flipped without pre-processing. This makes the stud bump flip chip model fast, efficient, and flexible for product development, prototyping and low to medium volume production, while easy to scale up to high volume wafer-based production with automated equipment.

Although stud bumping is fairly well developed, what is not yet established is a connection socket that can receive stud bumps in a reliable and reworkable manner.

Therefore, what is needed is a compliant and reworkable connection socket for electrically connecting stud bumped IC devices to a host system (e.g., a testing system, or a PCB of an electronic device).

SUMMARY OF THE INVENTION

The present invention is directed to a socket that facilitates solderless connection of an electronic device (e.g., an integrated circuit (IC) chip) to a host system (e.g., a printed circuit "motherboard" of an electronic system such as a digital computer, or a printed circuit test board of a testing system). In particular, the present invention is directed to a socket that provides a reliable, reworkable electrical connection to a stud bump (or other metal wire column or similar metal structure extending from the electronic device) when the electronic device is mounted onto the host system. The present invention is also directed to an assembly including the electronic device and host system, and to an array of sockets arranged to receive a corresponding array of stud bumps.

According to an aspect of the invention, the socket includes a three-dimensional (e.g., cylindrical or cubical) hollow metal frame that is either supported by an underlying structure or free-standing that is formed by plating metal over a patterned template structure. The metal frame includes side walls that extend away from the underlying

host substrate, and a contact structure located at the upper (i.e., free) end of the side walls. The contact structure defines an opening through which a stud bump can be inserted into a central chamber of the metal frame, which is surrounded by the side walls of the metal frame. The side walls and/or the contact structure are formed such that when the tip end of the stud bump is inserted into the central chamber, at least one of the base structure and the sidewall of the stud bump abuts the contact structure at two or more contact points, thereby ensuring that if one contact point has an intermittent loss of contact or increase in resistance, the other contact point(s) continue to handle the electrical load. Accordingly, the present invention provides a mechanism for electrically and mechanically connecting a "stud bumped" electronic device to a host system without solder, and with compliance that accommodates thermal expansivity mismatch, mechanical imperfections, and in a manner that adsorbs mechanical shock. In addition, the present invention facilitates reworking a packaged integrated circuit without having to heat the part, clean, and resolder.

According to an aspect of the present invention, socket fabrication includes forming a layer of negative-acting resist material (e.g., a negative, epoxy-based photoresist material such as SU-8, which is produced, for example, by MicroChem Corp. of Newton Mass., USA) adjacent to a contact pad exposed on a surface of the host system substrate (e.g., PCB), and then masking the upper surface of the negative-acting resist material layer such that a predetermined pattern of the resist material is exposed through the mask. The exposed negative-acting resist material is then illuminated through the patterned opening, thereby developing a region of the negative-acting material that corresponds to a desired patterned template structure. The developed regions of the negative-acting resist material exhibits reentrant sidewalls (i.e., such that the cross-section of the sidewall at the lower end is thinner than at the upper end). The non-exposed portion of the negative-acting resist material is then removed using known techniques, thereby exposing the patterned template structure. The metal frame is then plated over the exposed surface of the patterned template structure using known electroplating or electroless plating techniques. Thus, in this embodiment, the resulting socket utilizes a metal frame to provide electrical contact between the stud bump and the host system, and the patterned template structure to support the metal frame. According to an alternative embodiment, the patterned template structure is formed using an elastomeric material, such as Silicone (poly-dimethylsiloxane (PDMS)).

According to another embodiment, a socket includes a substantially cylindrical, relatively thick main wall surrounding a central cavity, and several relatively narrow, flexible membranes extending from the main wall into the central cavity. In one embodiment, the main wall and membranes are formed by fabricating a nonconductive, patterned template structure using, e.g., SU-8, and then made conductive by forming an external metal shell (frame) by electroplating or electroless plating. During subsequent use, the tip end of the stud bump enters the central chamber and contacts one or more of the membranes, causing the contacted membranes to bend toward the main wall. The lateral positioning accuracy of the stud bump can be more relaxed in this embodiment because of the relatively high flexibility of the membranes.

According to an alternative embodiment of the present invention, the patterned template structure is removed (e.g., dissolved or etched) after the metal frame is formed. In particular, a portion of the plating mask is formed on the

patterned template structure to produce an opening that exposes the patterned template material after the plating process is completed. The patterned template material is then removed through this opening to produce a socket structure that includes only a free-standing metal frame on the host substrate, which provides a connector having less stress and more flexibility than the retained structure. In one exemplary embodiment, the free-standing metal frame includes dual, coaxial side walls that are separated by a groove, and the contact structure of the socket is provided by upper edges of the inner side wall. In other embodiments, the metal frame includes one or more contiguous vertical side walls surrounding a hollow central cavity, and a horizontal upper wall that defines several cantilevered contact structures having fixed ends connected to the side walls, and free ends extending over the central cavity. Slits or other openings are defined between the cantilevered contact structures, through which the sacrificial patterned template material is removed, e.g., by dissolution or plasma etching. During subsequent use, the tip end of the stud bump enters the central cavity by pressing downward against one or more of the cantilevered contact structures, causing the contacted structures to bend downward into the central cavity.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings, where:

FIG. **1** is an exploded perspective view showing a socket and stud bump according to an embodiment of the present invention;

FIG. **2** is a perspective view showing an assembly including the socket and stud bump of FIG. **1**;

FIG. **3** is an exploded perspective view showing a socket array according to another embodiment of the present invention;

FIGS. **4**(A) and **4**(B) are cross sectional side views showing a row of the array of FIG. **3** during a mounting process;

FIGS. **5**(A), **5**(B) and **5**(C) are cross sectional side views showing the deposition of a negative-acting material and subsequent formation of a mask pattern during the fabrication of a patterned template structure according to an embodiment of the present invention;

FIG. **6** is a top plan view showing a mask pattern utilized in the process of FIG. **5**(C);

FIGS. **7**(A) and **7**(B) are cross sectional side views showing the development and subsequent removal of negative-acting material to form a patterned template structure;

FIGS. **8**(A), **8**(B), **8**(C) are cross sectional side views showing the formation of a metal frame over the patterned template structure of FIG. **7**(B) according to an embodiment of the present invention;

FIGS. **9**(A), **9**(B), **9**(C) are cross sectional side views showing the formation of a metal frame according to an alternative embodiment of the present invention;

FIG. **10** is a perspective view showing a socket and stud bump according to another embodiment of the present invention;

FIGS. **11**(A) and **11**(B) are top plan views showing the socket of FIG. **10** during use;

FIGS. **12**(A), **12**(B), and **12**(C) are perspective views showing fabrication of a socket according to an embodiment of the present invention;

FIGS. **13**(A) and **13**(B) are cross sectional side views showing the socket of FIG. **12**(C) during use;

FIG. **14** is a top plan view showing a socket according to another embodiment of the present invention; and

FIG. **15** is a top plan view showing a socket according to yet another embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded perspective view showing a socket **100** that makes sliding contact to a stud bump **150** according to an embodiment of the present invention. Referring to the upper portion of FIG. **1**, stud bump **150** includes a relatively wide base section **151**, an elongated (tapered) body **152** extending from base section **151**, and a tip **157** located at a free (tip) end of elongated body **152**. Stud bump **150** is formed according to modified wire-bonding techniques. Socket structure includes a metal frame **110** including at least one side wall **112** surrounding a central chamber **125**, and a contact structure **115** located at an upper end **114** of side wall **112**. Contact structure **115** defines an opening **117** that communicates with central chamber **125** to facilitate insertion of stud bump **150** along a central axis X.

According to an aspect of the present invention that is described below in additional detail, contact structure **115** is formed such that when tip **157** of stud bump **150** is inserted into central chamber **125**, base section **151** and/or elongated body **152** of stud bump **150** abut contact structure **115** at multiple contact points. This multiple contact objective is achieved by providing several contact protrusions **116** that extend from side wall **112** toward opening **117**. In particular, contact structure **115** is formed such that opening **117** defines a clover-like shape, with contact protrusions **116** forming convex portions of the clover shape that extend relatively close to central axis X, and concave portions **118** of contact structure **115** being located relatively far from central axis X. By providing multiple contact protrusions **116** arrayed around opening **117** in this manner, socket **100** ensures reliable electrical contact between stud bump **150** and socket **100**, even if one contact point experiences an intermittent loss of contact, or increase in resistance.

FIG. **2** is a cross-sectional side view illustrating an assembly **200** illustrating the manner in which socket **100** facilitates a compliant, direct, reworkable connection between a host system (e.g., a printed circuit board (PCB)) **230** and an IC chip (electronic device) **210** for testing, burning in, and packaging.

Referring to the upper portion of FIG. **2**, base section **151** of stud bump **150** is mounted onto a surface **212** of IC chip **210** such that base section **151** is in electrical contact with a die bonding pad **214**. Those skilled in the art will recognize that die bonding pad **214** is electrically connected to associated I/O circuitry (not shown) that is provided on IC chip **210** according to known techniques. Note that, in FIG. **2**, stud bump **150** is depicted in an enlarged form (i.e., relative to electronic device **210**) for illustrative purposes. In one embodiment, the overall length of stud bump **150** (i.e., from surface **212** to tip **157**) is approximately 25 microns. Other dimensions shown in the various figures are similarly distorted for illustrative purposes.

Socket **100** includes a patterned template structure **120** formed on an upper surface **231** of host system **230**, and metal frame **110** comprises a metal layer formed (e.g., plated) over an outer surface of patterned template structure **120**. As described in additional detail below, patterned template structure **120** is formed from a negative-acting photoresist material, and in the present embodiment comprises a continuous wall structure (i.e., a generally annular wall or a contiguous set of wall sections) surrounding central chamber **125**. Note that central chamber **125** is substantially symmetrical around and defines central axis X, which in turn extends substantially perpendicular to surface **231** of host system **230**. Metal frame **110** includes an outer base portion **111** formed on surface **231**, an outer side wall **112-1** formed on an outside surface of template structure **120** and extending between lower end portion **111** and an upper end **114**, an upper wall (contact structure) **115** extending over an upper end of patterned template structure **120**, an inner side wall **112-2** formed on an inside surface of template structure **120** and extending downward from an inner edge of upper wall **115**, and an inner base portion **119** connected to a lower edge of inner side wall **112-2** and formed on surface **231**. Upper wall **115** defines clover shaped opening **117**, as shown in FIG. **1**, that communicates with central chamber **125**, which is effectively defined by inner side wall **112-2** and inner base portion **119** of metal frame **110**. Inner side wall **112-2** has a horizontal cross section that is essentially identical to clover shaped opening **117**, thereby including concave and convex wall sections. The upper ends of the convex wall sections define concave portions **118** of upper wall **115**, and the upper ends of the convex wall sections define convex sections (contact protrusions) **116** of upper wall **115**. Accordingly, contact structure **115** and inner side wall **112-2** are formed such that, when the tip **157** of stud bump **150** is inserted through opening **117** into central chamber **125**, at least one of base section **151** and elongated body **152** abut contact structure **115** at multiple contact points (e.g., as shown in FIG. **2**, contact points C1 and C2) that correspond to the upper convex portions of inner side wall **112-2** and the innermost portions of contact protrusions **116**, thereby providing the reliable connection between stud bump **150** and socket **100**.

Note that host system **230** includes one or more contact pads (e.g., outer contact pad **232** and inner contact pad **233**) exposed on upper surface **231** and contacted by at least one of outer base portion **111** and inner base portion **119** of metal frame **110**. Host system **230** is constructed according to known printed circuit board (PCB) techniques to include a series of conductors **234** that are embedded in an insulating material **235** (e.g., CR4) for transmitting electrical signals between socket **100** and selected system electronics (not shown). In one embodiment, these system electronics include test equipment that is configured to transmit and/or receive test signals utilized by electronic device **210** according to known techniques.

In accordance with an embodiment of the present invention, patterned template structure **120** is formed from a negative acting photoresist material (e.g., SU-8) in the manner described in detail below. When such a negative acting material is used, the resulting wall structure exhibits a relatively narrow thickness W1 adjacent to its lower end (i.e., adjacent to upper surface **231** of host system **230**), and a relative wide thickness W2 adjacent to its upper end (i.e., adjacent upper wall **115**). This reentrant wall shape makes the overall size of socket **100** wider near upper end **114** than adjacent to base portion **111**, which, in combination with the tapered shape of stud bump **150**, allows stud bump **150** to center to socket **100** as stud bump **150** is inserted into central chamber **125**, thus allowing contact pressure on stud bump **150** to develop as well.

In an alternative embodiment (not shown), the patterned template structure can be formed using an elastomeric material, such as Silicone (poly-dimethylsiloxane (PDMS)),

but such a patterned structure may not provide the advantages of the reentrant wall shape described above.

In one embodiment, stud bump **150** is approximately 25 microns in length, and adjacent stud bumps in the predetermined pattern are separated by approximately 100 to 500 microns. In one embodiment, the depth of central chamber **125** of each socket **100** (i.e., measured along central axis X; see FIG. **1**) exceeds length of stud bumps **150** in order to ensure that the contact points are between upper wall **115** of metal frame **110** and base portion **151** of each stud bump **150**. In one embodiment, each socket **100** has a height of about 200 microns (or other suitable distance determined by the material used to form patterned template structure **120**), and metal frame **110** is formed with a metal plate thickness of 10 microns. The resulting structure exhibits a deflection of about 5 microns during insertion. In one embodiment, metal frame **110** is plated Nickel (Ni), which ensures a contact force of about 0.2 grams at each contact point. By providing multiple contacts in this manner, and utilizing gold passivation, the resulting socket assembly should assure reliable electrical contact for some applications. Different geometries may be used to increase the spring constant of the socket if needed.

FIG. **3** is an exploded perspective view showing a socket array **300** formed on host system **230** for receiving and electrically connecting an electronic device **210** (e.g., a "flip-chip" IC device). Electronic device **210** includes an array of stud bumps **150** arranged in a predetermined pattern and mounted in the manner described above. As described above, each stud bump **150** (e.g., stud bump **150-1**) includes an elongated body **152** extending between a base section **151** and a tip end **157**. Socket array **300** includes multiple sockets **100** arranged on an upper surface of host system (substrate) **230** in the same pattern as that of stud bumps **150**. As described above, each socket **100** (e.g., socket **100-3**) includes a metal frame **110** having at least one side wall **112** including a fixed end **111** connected to the substrate surface, and a free end **114** positioned away from the substrate surface. Side wall **112** surrounding an elongated central chamber **125**, and a contact structure **115** located at free end **114** of side wall **112** defines an opening **117** that communicates with central chamber **125**. Each socket **100** of socket array **300** is constructed such that when tip end **157** of a corresponding stud bump **150** is inserted into its central chamber **125**, at least one of the base section **151** and the elongated body **152** of the corresponding stud bump abuts the contact structure at multiple contact points.

In an exemplary embodiment, the area of each socket **100** of array **300** is approximately 150 by 150 microns. The realizable pitch of such an array would be on the order of several hundred microns. For area array interconnect this would be able to accommodate approximately one thousand sockets **100** on a 1 cm×1 cm die, although the present inventors envision the use of their invention on dies considerably smaller than 1 cm^2. For example, many components in handheld devices (e.g., personal digital assistants) are on the order of a fraction to a few square millimeters.

Preliminary calculations suggest that the assembly connections between the stud bumps (pins) and sockets would be highly reliable and substantially shock resistant. Assuming a coefficient of friction of 0.5, and four contact points per pin/socket connection, the insertion force for a 30 pin/socket array would be about 12 grams. The mass of the silicon die for such a part is only on the order of a few milligrams. A rudimentary model of the device is summarized below in Table 1. The computed properties indicate that it would take a shock of hundreds or thousands of g's to dislodge the IC chip from the host system, thereby indicating that socket array **300** provides a highly reliable connection structure. Note that one could always include a simple retaining clip or some corner bonds on the part (IC) or host to further improve the shock resistance of the socketed part, while still keeping it fairly easy to replace a failed part if needed.

TABLE 1

Rudimentary Socket Mechanical Model

Input Parameters Dimensions	Computed Properties Computed Dimensions
Height: 200 um	Spring Constant: 0.04 gm/um
Width: 50 um	Contact Force: 0.20 gm
Thickness: 10 um	Insertion Force: 12.0 gm
Deformation: 5 um	
Contacts per pin: 4	Pin Spacing: 258 microns
Chip Area: 2 mm^2	Chip Mass: 0.00233 gm
Number of Pins: 30	Dislodge acceleration: 5132 g's
Chip Thickness: 0.5 mm	
Material: Nickel	
Material Modulus: 250 GPa	
Friction Coefficient: 0.5	
Si density: 2.33 gm/cm^3	

In addition to providing a highly reliable and shock-resistant solderless connection structure, socket array **300** accommodates thermal expansivity mismatch and mechanical imperfections of the associated stud bump pattern, thereby facilitating repeatable connections between electronic device **210** and host system **230** under a variety of conditions, some of which are described below with reference to FIGS. **4**(A) and **4**(B).

FIGS. **4**(A) and **4**(B) are cross sectional side views showing a row of array **300** (FIG. **3**) including sockets **100-1** through **100-3** and stud bumps **150-1** through **150-3**. Referring to the left side of FIG. **4**(A), socket **100-1** and stud bump **150-1** represent the nominal arrangement in which stud bump **150** is substantially aligned with the axis X of central chamber **125-1**, and the connection process proceeds substantially as described above to produce the multiple contact connection indicated in FIG. **4**(B) and described in detail above. In contrast, as indicated in the center of FIG. **4**(A), the location of stud bump **150-2** is slightly displaced from its ideal position (indicated by dashed outline **115-2**A) due, for example, to thermal expansivity mismatch and/or mechanical imperfections (e.g., erroneous placement by the wire bonding tool). The socket array accommodates such alignment errors through the resilient deformation and the multiple contact point arrangement associated with the socket **100-2**. In particular, as indicated in FIG. **4**(B) due to its reentrant shape and compliant structure, side wall **112-2**A deforms to accommodate the misalignment of stud bump **150-2** as it enters central cavity **125-2**, thereby providing at least one reliable connection between base section **151-2** and contact structure **115-2**. Referring to the right side of FIG. **4**(A), stud bump **150-3** includes a tip **157-3** that is bent away from the ideal shape (indicated by dashed outline **115-3**A) due to mechanical imperfection arising during or after the modified wire-bonding production process. The socket structure of the present invention accommodates such imperfections by deforming to accommodate bent tip **157-3** as it enters central cavity **125-3**, thereby providing reliable connections between at least one of tip **157-3** and inner side wall **112-3**B, and/or base section **151-3** and upper wall **115-3**. Note that the resilient nature of sockets **100-1** through **100-3** facilitate repeated removal and insertion of stud

bumps **150-1** through **150-3**, thereby facilitating the reworking of the assembly without having to heat, clean, and resolder the connection.

An exemplary manufacturing process for producing socket **100** (described above) will now be described with reference to FIGS. **5**(A) through **8**(C).

FIGS. **5**(A), **5**(B) and **5**(C) are cross sectional side views respectively depicting the deposition of a negative-acting photoresist material layer **510** over upper surface **231** and contact pads **232** and **233** of host system **230**, and the subsequent formation of a mask pattern **520** on an upper surface **515** of layer **510** (FIG. **5**(C)). In one embodiment, the negative-acting photoresist material used to form layer **510** comprises a negative, epoxy-based photoresist material such as SU-8 having a thickness T_{SU-8} of approximately 200 microns. SU-8 is typically applied in liquid form, so it starts with a high degree of planarity. The SU-8 can be applied over a wide range of thicknesses depending on the spin speed and viscosity during the application process.

As indicated in FIGS. **5**(C) and **6** (which is a top plan view), mask **520** is patterned to include a main mask portion **520**A defining a window **525**, and a clover-shaped mask portion **520**B that is centered inside of window **525**. Note that a patterned surface region **512** of negative-acting photoresist material layer **510** is exposed through window **525**.

FIGS. **7**(A) and **7**(B) are cross sectional side views showing the development and subsequent removal of the material layer to complete the fabrication of the patterned template structure **120**. As indicated in FIG. **7**(A), sections **515** of material layer **510**, which lay below exposed patterned surface region **512**, are subjected to illumination by way of light beams **530**. Note that, due to the gradually diminishing light exposure, sections **515** have a tapered (reentrant) shape in which the upper regions (i.e., adjacent surface region **512**) are wider than the lower regions. Mask **520** and the underlying, non-exposed regions of material layer **510** are then removed according to known techniques, thereby leaving patterned template structure **120** (FIG. **7**(B)) on host system **230**. Note that patterned template structure **120** is formed on or adjacent to contact pads **232**, and or define central chamber **125**, which exposes central contact pad **233**.

FIGS. **8**(A) through **8**(C) are cross sectional side views depicting the formation of a metal frame over patterned template structure **120** according to another aspect of the present invention. First, as shown in FIG. **8**(A) an optional seed layer **540** is formed over patterned template structure **120**, contact pads **232** and **233**, and other exposed structures and surfaces of host system **230**. A sputtered seed can be used to electroplate onto the SU-8. Patterned initiators could also be used for electroless plating. Referring to FIG. **8**(B), a plating mask **550** is then formed around patterned template structure **120**, and metal frame **110** is then formed over patterned template structure **110** and the surrounding exposed structures by electroplating or electroless plating. Nickel phosphorous passivated with gold is a suitable candidate for the plated connector metallurgy, but other possibilities will be apparent to skilled practitioners. Some versions of plating, including electroplating, tend to deposit metal faster at sharp features. This could be used to advantage to produce a structure with reentrant sidewalls, as it will produce thicker metal on the upper surface of patterned template structure **120** and other horizontal surfaces, and thinner metal along the relatively vertical side wall surfaces. As indicated in FIG. **8**(C), the manufacturing process of socket **100** by removing the plating mask and underlying seed material, e.g., by etching, from around metal frame **110** and patterned template structure **120**.

Placing resist onto a high aspect, reentrant structure, such as the various socket structures proposed herein, might be considered problematic. Spray coated resist could be considered as one option. Recent discussions have revealed, however, that equipment has been developed for reliably and inexpensively coating parts with electrodeposited resist. In this process, photoresist coats any metal surface that is electrically connected to the cathode of the resist depositing system.

FIGS. **9**(A) through **9**(C) are cross sectional side views showing the formation of a socket **100**A (FIG. **9**(C)) having an alternative free-standing metal frame **110**A according to an other embodiment of the present invention. This embodiment recognizes that there are methods for and potential advantages to making a socket structure in which the internal polymer framework is removed, either fully or partially from the completed socket structure. As indicated in FIG. **9**(A), when plating mask **550** is formed as described above with reference to FIG. **8**(A), mask portions **555** are formed on an upper surface **121** of patterned template structure **120**. Subsequent formation of metal frame **110**A produces an open-ended structure in which upper surface **121** remains free of plated metal. Subsequent removal of the masking material (and seed material) leaves the structure shown in FIG. **9**(B); i.e., where patterned template structure **120** is exposed through metal frame **110**A by way of upper surface **121**. As indicated in FIG. **9**(C), patterned template structure **120** is then removed using an etchant or solvent that enters through the open upper end of metal frame **110**A and clears away the material from between outer side wall **112-1** and inner side wall **112-2**, thereby forming a groove **113**. Note that, in this embodiment, contact structures **115**-**A1** and **115**-**A2** are formed by the upper edges of outer side wall **112-1** and **112-2**, respectively, with contact structure **115**-**A2** providing the primary contact structure for socket **100**A. Note also that contact structure **115**-**A2** may be enhanced by forming smaller mask portions **555** that expose portions of patterned template structure **120**, thereby resulting in horizontal flange structures that extend outward from the upper edges of inner side walls **112-2**. Moreover a single-wall socket structure may be formed by extending the masking material between mask portions **550** and **555**, thereby preventing the formation of outer side wall **112-1** (i.e., such that plated material is only retained on the inside surface of patterned template structure **120**, and the resulting socket includes only inner wall **112-2**, inner base portion **119**, and a horizontal flange structure extending from the upper edge of inner wall **112-2**, if provided). The potential advantages of socket **100**A include less internal stress during thermal cycling and greater flexibility. These features could prove to be advantageous particularly for structures that undergo solder reflow, either for soldering the socketed components themselves, or other parts on the same board.

There are a couple of ways that sockets of the present invention could be used for test or burn-in for purposes of verifying an IC chip, and then producing a complete metallurgical contact through soldering. One possible method involves tinning either the stud bump, the socket, or both the stud bump and socket with plated solder, and then reflowing the solder once the IC chip performance is verified.

Sockets produced in accordance with the present invention are fairly scalable to smaller dimensions and higher density than those of the exemplary embodiments discussed above. For example, the stud bumps could be replaced with plated columns, and the lateral dimensions of the socket

could be scaled down. The limit on scaling may stem from the tolerances of the components, and the placement accuracy of the tool that brings the parts together.

Further, while the exemplary embodiments described above are directed to sockets having clover-shaped openings, other socket structures may be produced that incorporate the spirit and scope of the present invention. Several such alternative socket structures are introduced below with reference to FIGS. **10** through **15**.

FIG. **10** is a perspective view showing a socket **100**C and stud bump **150** according to another embodiment of the present invention. Socket **100**C includes a metal frame **110**C having a relatively thick (e.g. 10–50 micron), substantially cylindrical wall **112**C surrounding a central cavity (chamber) **125**C, and several relatively narrow (e.g. 1–5 microns) flexible membranes **116**C extending from main wall **112**C into central cavity **125**C. Cylindrical wall **112**C defines an opening **117**C at its upper end **114**C that communicates with central cavity **125**C. An upper edge **115**C and/or flexible membranes **116**C form the contact structure of socket **100**C. In one embodiment, cylindrical wall **112**C and membranes **116**C are formed using a negative-acting photoresist material (e.g., SU-8) such that these structures define reentrant cross-sections that are wider near upper end **114**C and narrower near lower end **111**C. By carefully selecting an appropriate width, membranes **116**C can be formed such that they are not anchored to the underlying substrate due to the reentrant profile of the negative-acting photoresist, thereby providing additional flexibility to membranes **116**C. The resulting structure is then over-plated (or partially over-plated) with a metal such as nickel and/or gold in the manner described above.

FIGS. **11**(A) and **11**(B) are top plan views showing socket **100**C during use. FIG. **11**(A) shows a point during the insertion process when a relatively narrow portion of stud bump **150** has entered central cavity **125**C. As indicated in FIG. **11**(B), as stud bump **150** is inserted further into central cavity **125**C, the wider outer wall of stud bump **150** contacts and presses against flexible membranes **116**C, thereby forcing membranes **116**C outward toward cylindrical wall **112**C (i.e., in the direction indicated by the arrows). Note that the wide opening **117**C defined by main wall **112**C and the flexibility of membranes **116**C facilitate relaxing the lateral positioning accuracy of stud bumps **150**.

FIGS. **12**(A) through **12**(C) are perspective views showing fabrication of another socket according to yet another embodiment of the present invention. The process begins by forming a column **120**D of sacrificial material on a host system surface **231**D according to any of the methods described above (FIG. **12**(A)). Next, as indicated in FIG. **12**(B), a plating mask is provided that includes a peripheral portion **550**D surrounding column **120**D, and an X-shaped portion **555**D that is patterned on an upper surface of column **120**D. A metal frame **110**D is then formed by plating a metal layer over the exposed portions of column **120**D and removing the plating mask. As indicated in FIG. **12**(C), the resulting metal frame **110**D includes a base portion **111**D, a substantially cylindrical side wall **112**C surrounding the cylindrical template structure, and an upper wall (contact structure) **115**D that includes several wedge-shaped contact structures **116**D extending inward from upper edge **114**D and separated by an X-shaped opening formed by radial grooves **117**C. After forming metal frame **110**D, the sacrificial material used to form column **120**D (e.g., shown in FIG. **12**(A) is then dissolved or otherwise removed through radial openings **117**C, thereby forming a hollow cavity inside of metal frame **110**D.

FIGS. **13**(A) and **13**(B) are cross sectional side views showing socket **100**D during use. In particular, these figures show stud bump **150** as tip **157** is pressed against upper wall **115**D, thereby causing cantilevered contact structures **116**D to deflect downward into a central chamber **125**D defined by cylindrical side wall **112**D and upper wall **115**D.

FIG. **14** is a top plan view showing a socket **100**E according to yet another embodiment of the present invention. Socket **100**E includes an upper wall **115**E of a metal frame that is separated into eight wedge-shaped contact structures **116**E separated by radial grooves **117**E that operate substantially as described above with reference to FIG. **13**(B). Those skilled in the art will recognize that by forming an arbitrary number of radial grooves, a socket having any number of wedge-shaped contact structures can be produced.

FIG. **15** is a top plan view showing a socket **100**F according to yet another embodiment of the present invention. Socket **100**F includes a metal frame **110**F similar to that described above with reference to FIG. **14**, and includes substantially rectangular cantilevered contact structures **116**F are formed in parallel and are separated by parallel grooves **117**F. By offsetting the ends of cantilevered contact structures **116**F in the manner shown in FIG. **15**, a highly reliable contact structure is provided due to the increased likelihood that a stud bump will be contacted in two or more locations.

Although the present invention has been described with respect to certain specific embodiments, it will be clear to those skilled in the art that the inventive features of the present invention are applicable to other embodiments as well, all of which are intended to fall within the scope of the present invention. For example, while several sockets are described above with specific reference to cylindrical side walls, those skilled in the art will recognize that such side walls can be replaced with other contiguous wall arrangements such as oval walls and a contiguous series of straight walls arranged, for example, to form a square, pentagonal, or hexagonal structure. In addition, the specific contact structure geometries indicated in FIGS. **14** and **15** are intended to be exemplary, and may be modified to include, for example, curved spiral structures or zigzag structures. In addition, instead of vertical side walls, these structures may be formed with inward-slanting (positive sloped) sidewalls to allow for some compliant flexure involving the vertical length of the structure, which is further enhanced by forming slots that extend down the slanted side walls of the structure (i.e., such that base of the contact structures is located on the side walls). Moreover, the term "stud bump" as used herein is not intended to be limited to structures formed by modified wire bonding techniques, but also extends to similar metal structures, such as metal posts formed by electroplating. Finally, the reentrant wall structure described above may be formed using methods other than negative-acting resist materials, such as by image reversal, angular exposure, and variable depth of focus exposure.

The invention claimed is:

1. A socket for electrically connecting a stud bump mounted thereon, the stud bump including a base section and an elongated body extending between the base section to a tip end, the socket comprising a metal frame including an inner side wall portion surrounding a central chamber, an outer side wall portion surrounding the inner side wall portion such that the inner side wall portion is separated from the outer side wall portion, and a contact structure located at an upper end of the inner side wall, the contact structure defining an opening that communicates with the

central chamber, wherein when the tip end of the stud bump is inserted into the central chamber, at least one of the base section and the elongated body of the stud bump abut the contact structure at two or more contact points.

2. The socket according to claim **1**, wherein the contact structure comprises a plurality of contact protrusions extending toward the opening.

3. The socket according to claim **1**, further comprising a patterned template structure, wherein the metal frame comprises a metal layer formed on a surface of the patterned template structure.

4. The socket according to claim **3**,

wherein the patterned template structure comprises a continuous wall surrounding the central chamber,

wherein the inner side wall portion is formed on an inside surface of the continuous wall, and the outer side wall portion is formed on an outside surface of the continuous wall, and

wherein the contact structure comprises an upper wall of the metal frame extending between the inner side wall and the outer side wall.

5. The socket according to claim **1**,

wherein the inner side wall comprises a clover shaped cross-section including concave sections located relatively far from an axis defined by the central chamber, and convex sections located relatively close to the axis, and

wherein the upper wall includes contact protrusions extending over the convex sections of the inner side wall.

6. The socket according to claim **3**, wherein the patterned template structure defines a reentrant wall structure.

7. The socket according to claim **6**, wherein the patterned template structure comprises a negative-acting photoresist material.

8. The socket according to claim **6**, wherein the negative acting material comprises SU-8.

9. The socket according to claim **6**, wherein the patterned template structure comprises walls having a relatively narrow thickness adjacent to a lower end, and a relative wide thickness W**2** adjacent to the upper end.

10. The socket according to claim **3**, wherein the patterned template structure comprises an elastomeric material.

11. The socket according to claim **1**, wherein the metal frame further comprises a lower wall portion connected to a lower end of the inner side wall portion.

12. The socket according to claim **11**,

wherein the inner side wall portion comprises a clover shaped cross-section including concave sections located relatively far from an axis defined by the central chamber, and convex sections located relatively close to the axis, and

wherein the contact structure comprises an upper edge of the inner side wall portion at said convex sections.

13. The socket according to claim **1**, wherein the contact structure comprises a plurality of flexible membranes extending from the inner side wall portion into the central chamber.

14. The socket according to claim **13**, wherein each of the plurality of flexible membranes has a relatively narrow thickness adjacent to a lower end of the inner side wall portion wall, and a relative wide thickness adjacent to the upper end of the inner side wall portion wall.

15. An assembly comprising:

an electronic device including a stud bump, the stud bump including a base section attached to a surface of the electronic device, a tip end positioned away from the surface, and an elongated body extending between the base section and the tip end; and

a host system including:

a substrate; and

a socket mounted on a surface of the substrate, the socket comprising a metal frame including:

at least one side wall having a fixed end connected to the substrate surface and a free end positioned away from the substrate surface, the at least one side wall surrounding an elongated central chamber, and

a contact structure located at the free end of the at least one side wall, the contact structure defining an opening that communicates with the central chamber,

wherein the electronic device is connected to the host system such that the tip end of the stud bump is inserted through the opening into the central chamber of the socket, and such that the contact structure of the socket abuts at least one of the base section and the elongated body of the stud bump at two or more contact points.

16. A socket array for electrically connecting an electronic device including a plurality of stud bumps extending therefrom, the plurality of stud bumps being arranged in a predetermined pattern, each of the stud bumps including a base section and an elongated body extending between the base section to a tip end, the socket array comprising:

a substrate; and

a plurality of sockets arranged in the predetermined pattern on a surface of the substrate, each socket comprising a metal frame including:

at least one side wall having a fixed end connected to the substrate surface and a free end positioned away from the substrate surface, the at least one side wall surrounding an elongated central chamber, and

a contact structure located at the free end of the at least one side wall, the contact structure defining an opening that communicates with the central chamber,

wherein each socket of the socket array is constructed such that when the tip end of a corresponding stud bump is inserted into its central chamber, at least one of the base section and the elongated body of said corresponding stud bump abuts the contact structure at two or more contact points.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,118,389 B2
APPLICATION NO. : 10/871330
DATED : October 10, 2006
INVENTOR(S) : David K. Fork et al.

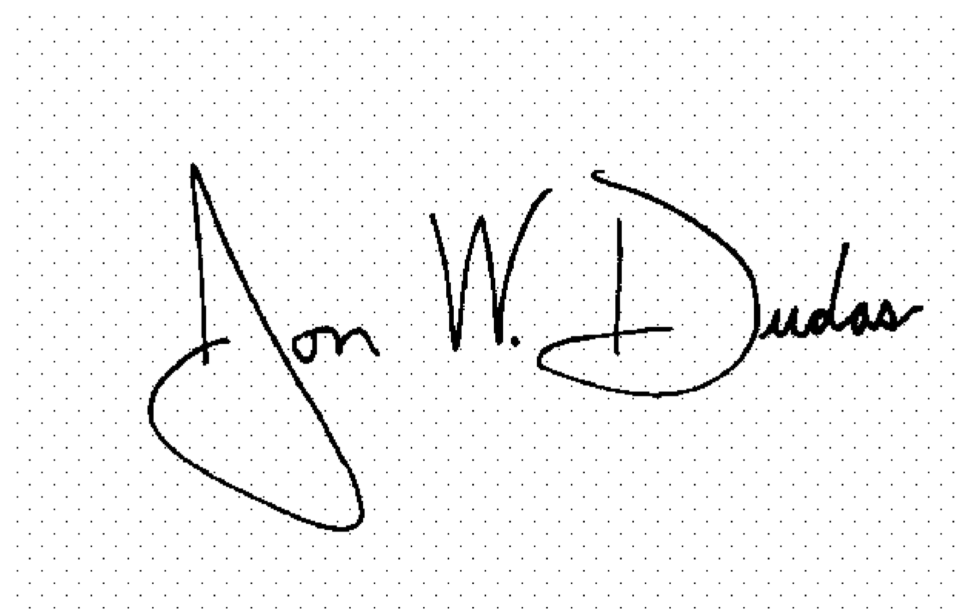
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1, line 2, insert as a new paragraph:

This invention was made with Government support under 70NANB8H4008 awarded by NIST. The Government has certain rights in this invention.

Signed and Sealed this

First Day of May, 2007



JON W. DUDAS

Director of the United States Patent and Trademark Office